12-2011

# Perception of Aquifer Depletion and the Effects of Land Use Change Across the Madaba Plain, Jordan

Mohammad Salem
*University of Arkansas, Fayetteville*

Perception of Aquifer Depletion and the Effects of Land Use Change

Across the Madaba Plain, Jordan

Perception of Aquifer Depletion and the Effects of Land Use Change
Across the Madaba Plain, Jordan

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Environmental Dynamics

By

Mohammad Salem
University of New Orleans
Bachelor of Arts in Anthropology, 1998
University of Arkansas
Master of Arts in Geography, 2002

December 2011
University of Arkansas

## Abstract

In Jordan, demand for water for agricultural purposes has put a high strain on aquifer resources. Water mining, erosion, and desertification have all increased as global temperatures rise. This along with fragmentation of the landscape have altered the environment in a profound way. The Madaba Plain was chosen for this study due to the agricultural activities that take place there, as well as the proximity to a number of population centers. The purpose of the study is to examine how fragmentation of irrigated landscape has affected the aquifers underneath, while taking into account perceptions of risk of the local population.

Data for the study was acquired through a number of sources. Demographic and Likert Scale data were obtained by distributing written surveys that participants completed and returned. Remotely-sensed data were obtained from the USGS through the glovis.gov website for the years of 1991, 1998, 2002, and 2006. Finally, groundwater data were obtained from the Ministry of Water and Irrigation in Amman.

The results of the study showed some surprising and unanticipated trends. Generally, the Likert scale answers had a low mean, and showed that respondents did not have much awareness about any of the hazards put before them. The awareness levels did demonstrate a geographic trend, where awareness generally increased from north to south. While landuse between the four time periods did not change significantly, depth to water measurements showed high variability. Analysis of continuity index for the study showed no significant relationships between fragmentation and water depth.

This dissertation is approved for
Recommendation to the
Graduate Council

Dissertation Director:

________________________________________

Dr. Thomas R. Paradise

Dissertation Committee:

________________________________________

Dr. Van Brahana

________________________________________

Dr. Jackson Cothren

**Dissertation Duplication Release**

I hereby authorize the University of Arkansas Libraries to duplicate this dissertation when needed for research and/or scholarship.

Agreed ____________________________________________
*Mohammad Salem*

Refused ____________________________________________
*Mohammad Salem*

**Acknowledgements**

I would like to thank God for giving me the opportunity to complete my education at the University of Arkansas.

I would also like to thank the Jordan Ministry of Water and Irrigation for their assistance in providing the data needed for this study. This study could not have happened with out their cooperation.

I would like to thank Abu Mohammad, Yasine, Ahmed, and others that helped me implement the surveys in Jordan.

I would also like to thank the faculty and staff at the University of Arkansas who have provided guidance throughout this study. This includes my colleagues at the Center for Advanced Spatial Technologies that assisted me with my many questions.

I would like to give thanks to the Middle East studies program as well as the King Fahd Center for Middle East and Islamic studies for years of support.

I would especially like to thank the members of my committee, Dr. Tom Paradise, Dr. Van Brahana and Dr. Jackson Cothren for their guidance throughout this process.

Finally, I would like to thank my friends and family who supported me through this journey.

## Dedication

I would like to dedicate this work to my wife, Hanadi Salem, whose love and support helped drive me to complete this body of work.  Thank you for all you have done for me.

## Table of Contents

## Tables

## Figures and Photographs

# Chapter 1: Introduction

Over the past 30 years, agricultural patterns in the Levant have changed dramatically due to reasons such as increasing population pressure, inheritance laws, and the modernization of agricultural equipment and methods. In many areas, this has led to over pumping of aquifers which is a serious problem to contend with considering the arid climate of the region. This study proposes to understand changes in irrigated agriculture in the Madaba Plain area in west-central Jordan and address some concerns such as water use, conservation and perception of availability.

Owing to the high demand for water in Jordan, the main concern of this project is to understand how agricultural fragmentation of the landscape is affecting water aquifers in the region. It is already known that aquifers are being mined at the rate of approximately 96 million cubic meters (MCM) annually (Abu-Rukah 2001). From 1985-1997, the annual water budget of Jordan increased from 639 MCM to 876 MCM (Dal Santo and El Naser 2001). To meet these increasing needs, groundwater withdrawals in 1997 consisted of approximately 486 MCM of Jordan's groundwater was withdrawn representing 55% of its water needs in 1997 alone. Aquifers from seven basins throughout the country are being over pumped at a rate of 135-225% (Dal Santo and El Naser 2001). Specifically, the three main basins of the study area were pumped at rates given in table 1.1 (from Abu-Rukah 2001).

**Table 1.1:** Water uses for 1997

| Water Basin | ***Drinking MCM*** | ***Industrial MCM*** | ***Irrigation MCM*** | ***Isolated Areas MCM*** | ***Total Abstraction MCM*** | ***Balance*** |
|---|---|---|---|---|---|---|
| Side Wadis | 4.914 | NA | 6.908 | NA | 11.822 | 3.178 |
| Amman-Zarqa | 63.424 | 6.004 | 67.994 | 0.014 | 137.436 | -49.936 |
| Dead Sea | 34.289 | 16.281 | 33.742 | 1.981 | 86.293 | -29.293 |

As can be seen, water demand in the Madaba plain region is already strained due to agriculture, as well as municipal needs. Projections of a 60% increase in pumping rates by 2025 for the country does not bode well for aquifers in the area that are already being depleted of fossilized water.

Overpumping of aquifers for agricultural purposes has numerous adverse effects, primarily that it causes a major decline in the water table (Goudie 2000). This in turn, may cause water mining to occur which is dangerous because in many cases the aquifer is damaged by compaction and no longer retains the ability to store water. The lowering of the water table leads to increased energy cost due to increased pumping. In Jordan, 20% of the overall energy use is dedicated solely to water pumping (Brooks 1997). Another concern is that a lower water table will allow pollutants to infiltrate deeper into the aquifer contaminating the fresh water for generations of water users.

Other concerns pertaining to the use of irrigation in this area is the risk of desertification. This has already occurred in some areas of the Madaba Plain. High evapotranspiration rates may leave saline residuals that have a two-fold effect. First, this would cause agriculturally productive soil to become useless. Second, increased runoff due to low frequency, intense high-magnitude storms that are typical of the region may have a scouring effect on the landscape (Thomas 1997).

Jordan, specifically the Madaba Plain, provides an excellent case study for this type of research for a number of reasons. The semi-arid climate of the Plain forces the local population to be cautious of overusing already stressed groundwater resources. Population pressure on water resources in Jordan began in the early 1960s and significantly grew until the mid-1970s. Municipal needs were given top priority by the government; however, allocations were allowed for the agricultural sector. At this time the agricultural sector was being fostered due to the employment generated, the stabilizing effects on the rural population and economic gains produced (Haddadin 2006). Competition for water resources between municipal needs and agricultural needs arose as early as the 1950s, when the municipal sector started to take away from the agricultural allocations. The construction of the King Talal Dam in north-central Jordan mitigated some of these problems.

Another critical factor for the selection of Jordan as the study site is the political climate within the region. Although there are underlying societal tensions within the country, Jordan is one of the more stable countries in the region, ranking 96 on the risk of failed states index (The Fund for Peace 2011). This makes it an attractive location for refugees of political strife that has plagued the area for the better part of recent history. As more people move from areas such as the Palestinian Territories, Syria, and Iraq, a higher strain is put on the already limited water and land resources.

The research takes a multidisciplinary approach looking to address groundwater and landuse concerns by examining perceptions of risk and analyzing remotely sensed data as well as groundwater data procured from the Ministry of Water and Irrigation. Many parts of the Middle East have experienced a modernization of the agricultural sector, which has allowed for an increase in agricultural production (Aswad 1971). As the landscape has changed from traditional to a more centralized farming strategy (figure 1.1), it is my contention that aquifer levels will show a corresponding fall in water table levels.

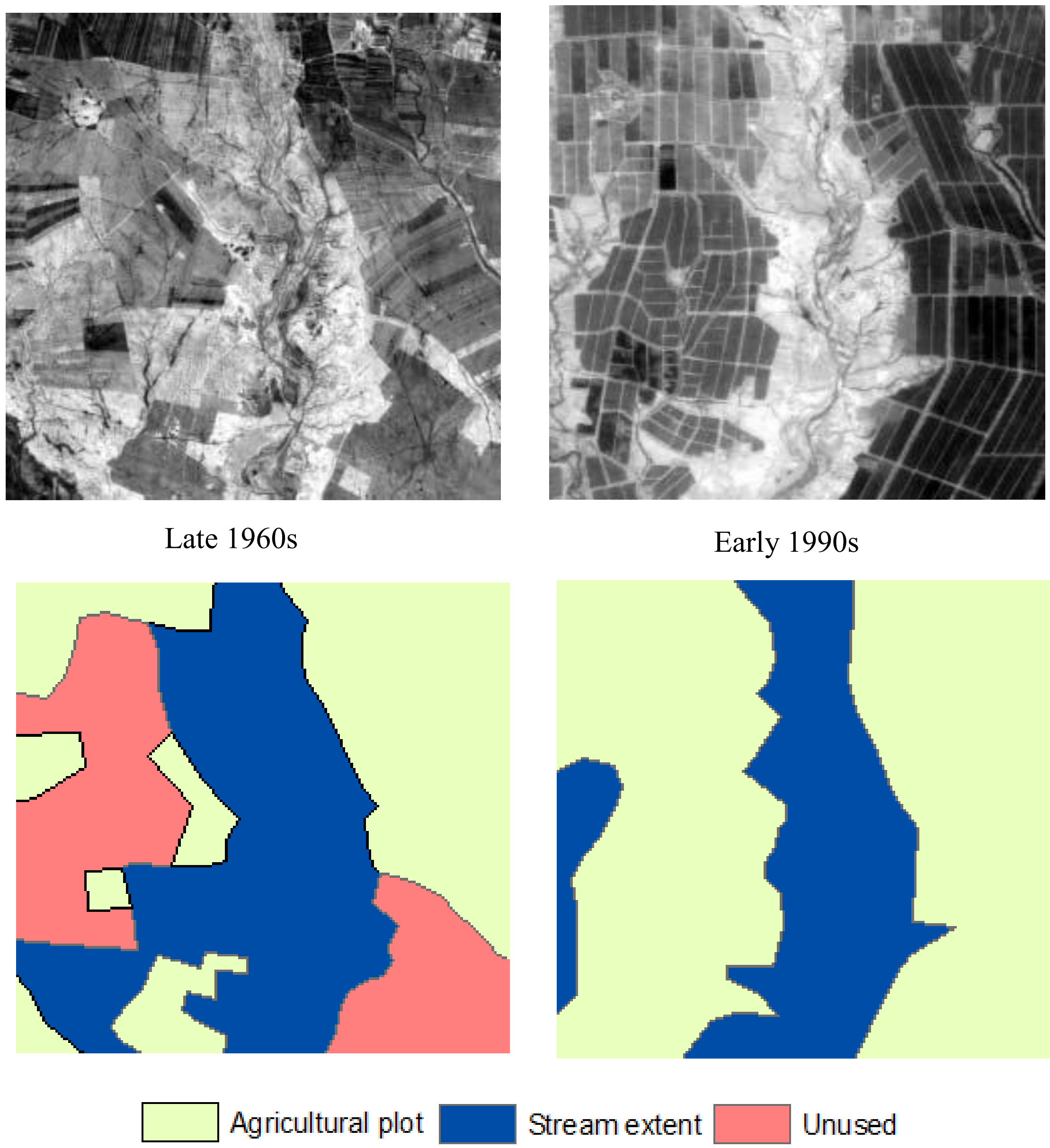



**Figure 1.1:** Changes in land use from a decentralized model (right figure) of agriculture to a more centralized form (left figure). Plots of land have gone from disordered organization to a linear organization running generally north to south. Note the stream extent has become smaller due to the engineering of agricultural practices (taken from Kouchoukos 2001).

To achieve the required results for analysis, a number of methods will be employed. First a written survey will be administered that focuses on demographic factors and perception of risk for a number of land and water resource categories. Along with this, a study will be completed that focuses on land use interaction with the underlying aquifer. The intention of this component of the study is to locate problematic land use practices and attempt to examine what risk is associated with that area.

This research is an innovative way to look at a worldwide problem at a local scale where water and land resources are scarce. Although landuse and water use studies have been done in the past, the addition of the perception of risk factor allows us to discern the way people think about and react to degradation of these overused resources. This in turn can shape future policy in areas such as resource use and education of natural resources within Jordan.

# Chapter 2: Study Area

## Location

The study site for this research is an area of 43 X 62 km, conforming to the physiographic boundaries of the Madaba Plain's watershed extents and drainage basin area. The study region boundary (figure 2.1) includes the thalweg of the Wadi Mujib, also known as the Arnon River to the south, extending east to subsume all agricultural lands in the Great Jordan Desert. The city of Amman is the northern extent of the boundary, while the western boundary is the western edge of the plateau that descends into the Jordan River Valley. The last boundary was selected because land over 25% slope is not considered to be arable (Sallaku et al. 2007). The majority of study area lies within the Dead Sea Basin. It is dominated by the Arnon River and is Jordan's primary agricultural region on the Madaba Plain. This study area was chosen due to its importance as the primary agricultural producing region and commercial water user in Jordan (Abbas 1989). The crop-producing area (and study site) is located above the B2/A7 Aquifer Complex, known as the Amman-Wadi Sir Aquifer in the region.

Thomas (1997) gives an overview of precipitation and effects of precipitation on landscape. He contends that there are 2 factors related to precipitation totals. The first is the Mediterranean Sea. During the winter, the temperate latitude climatic belt prevails and moist cool air is delivered from the Mediterranean (Martens 2001). The two most dominant weather patterns are the Cyprus low pressure system, which occur mainly over Turkey, and the Syrian low pressure system. The Syrian Lows are the second most frequent synoptic scale cyclone type and produce major floods over the Levant region (Dayan and Morin 2006).

The second factor, altitude,  affects rainfall distribution by way of the rain shadow phenomenon. In the Levant region, only Lebanon does not include areas of extreme aridity due to higher elevation.  Effects on the landscape in the region are governed by the intensity of rainstorms. High magnitude, low frequency storms are the norm in the region and are important to the geomorphologic process.  These storm events have a number of effects;  they assist in forming the many wadis (figure 2.2 and figure 2.5) associated with the region, accelerate weathering which produces more sediment debris (Brice 1978) and  also accelerate erosion of the thin layer of topsoil including the region around Madaba (Abbas 1989).  Furthermore, Maher (2005) asserts that the major events of land degradation in Jordan are not a function of increased precipitation, but a function of increased extreme events that interrupt prolonged periods of drought.  Changes in climate can have an effect on the frequency of extreme meteorological events (Arnell 1996).  These high magnitude events can further deteriorate soil quality by way of scouring the landscape of all fertile soils.

The Madaba Plain is considered to be the second most productive wheat growing area in Jordan, producing 700-800 kg/ha annually (Abbas 1989).  The yields of wheat are, in general, proportionate to the amount of precipitation on the Madaba Plain, which ranges between 300-350 mm annually (figure 2.3 and 2.6).  Overall, precipitation is relatively abundant on the higlands compared with the rest of the country (Haddadin 2006).  However even on the highlands, there is a trend where precipitation decreases  from north to south.  Overall, the total annual precipitation of Jordan is about 8.2 billion cubic meters, with ranges of 6-12 bcm for dry and wet years respectively (Haddadan 2006).  Evaporation rates follow the north to south trend with potentially 1,600 mm/yr being evaporated in the north to 4,000 mm/yr in the southern and eastern desert areas. These rates range from 5 to 80 times the corresponding average precipitation amounts (Haddadan 2006).


**Figure 2.1:** Study area extent of the Madaba Plain in Jordan.

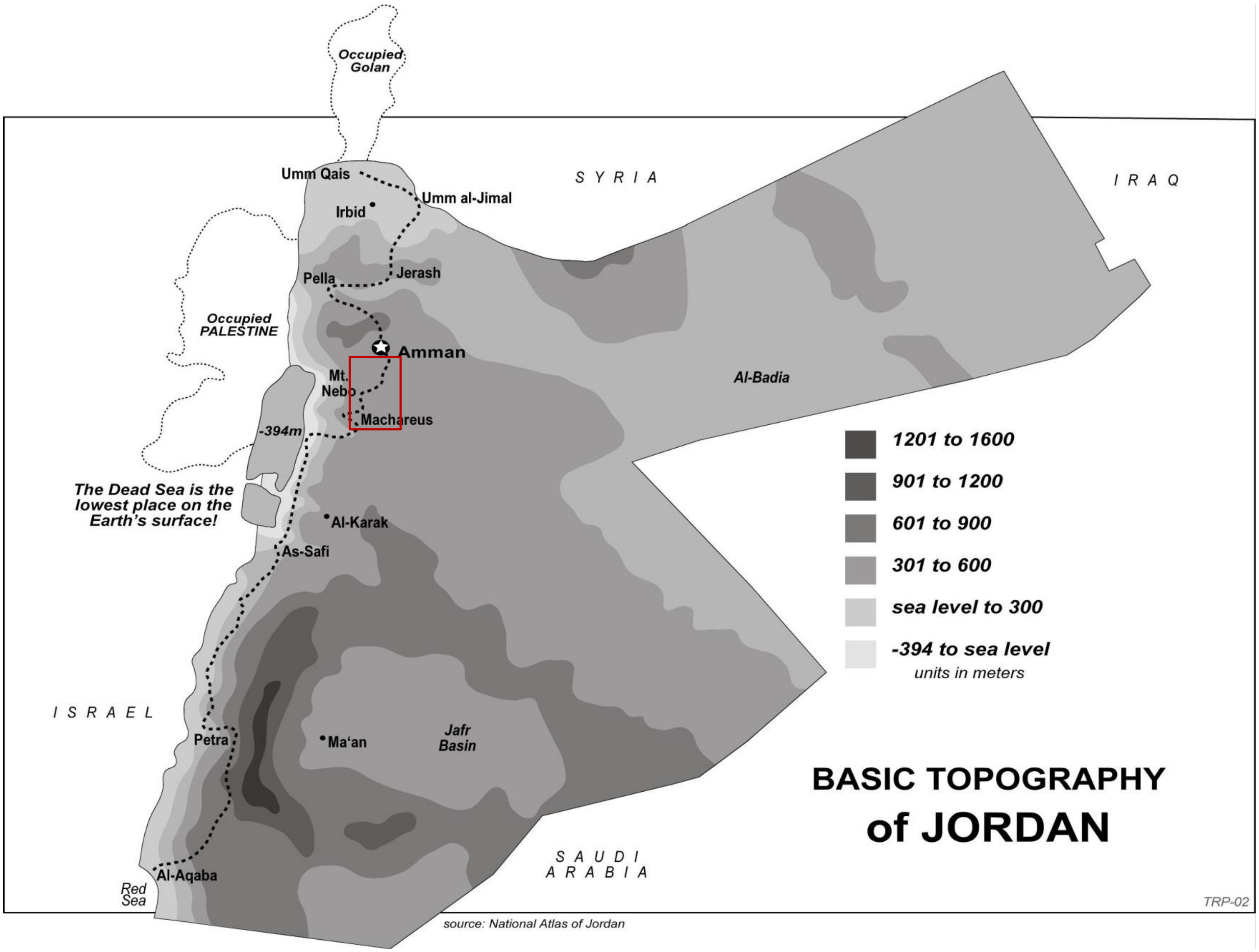



**Figure 2.2**: Relief map of Jordan (Paradise 2002).

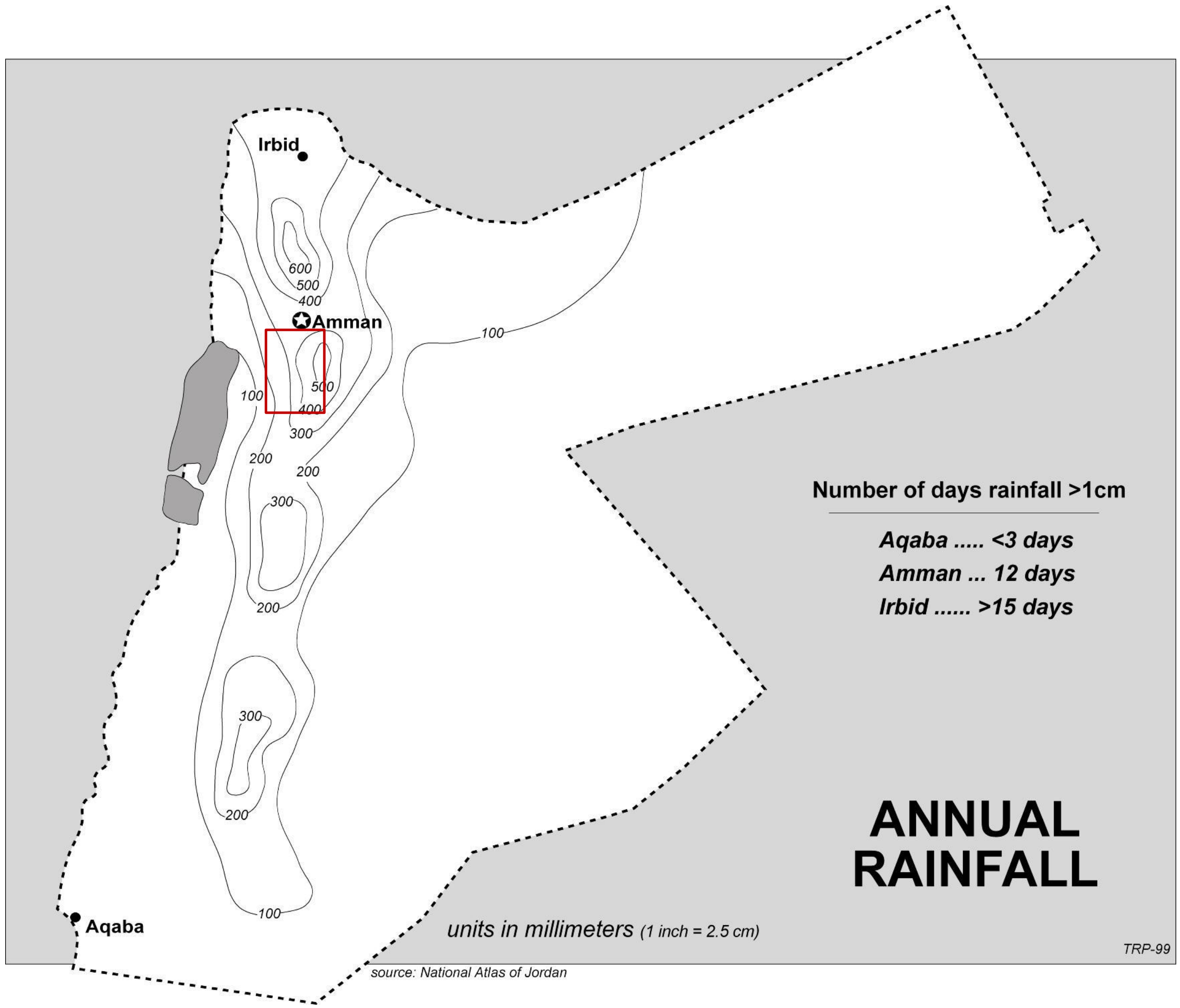



**Figure 2.3**: Annual Rainfall in Jordan (Paradise 2002).

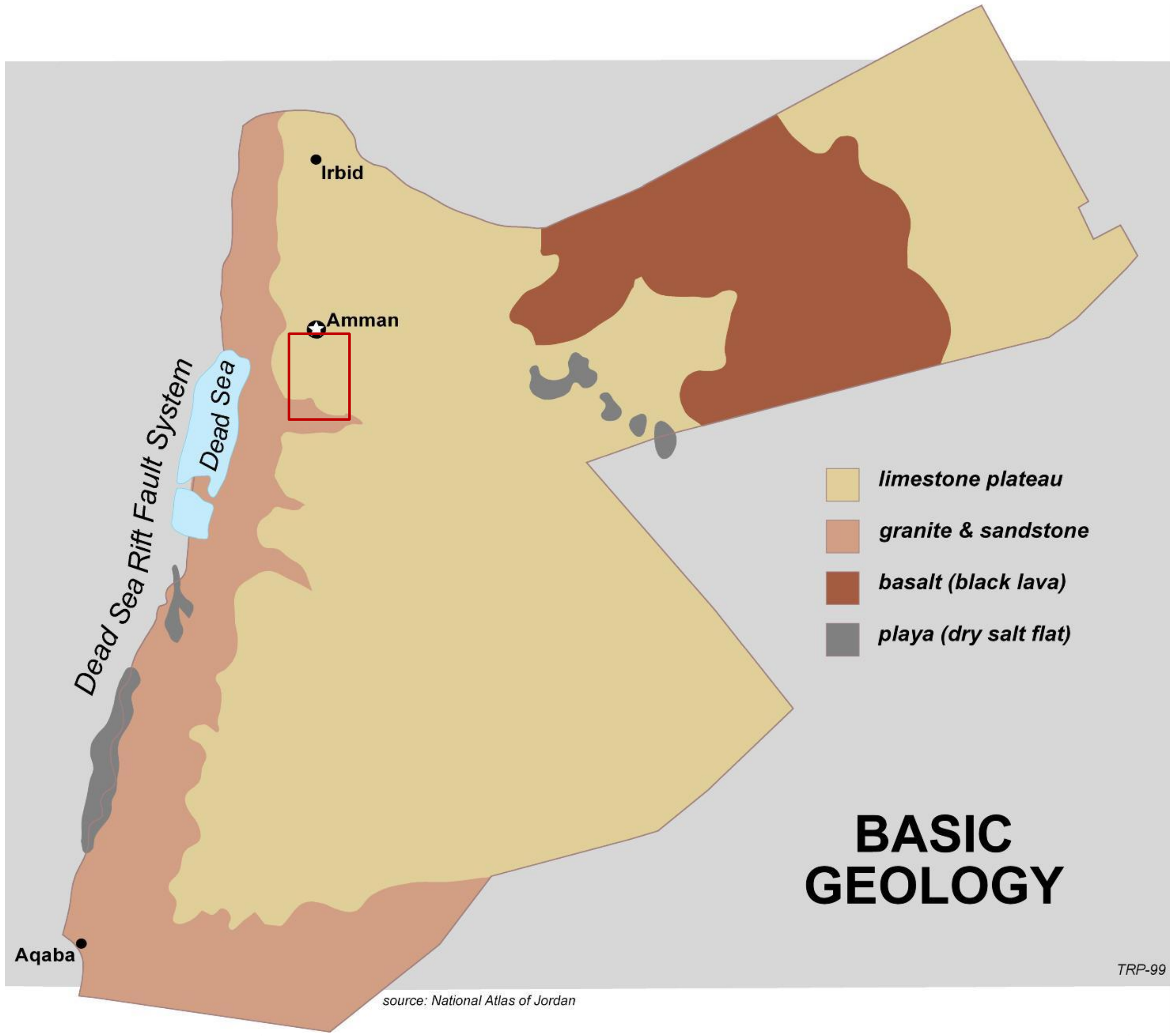



**Figure 2.4**: Basic Geology of Jordan (Paradise 2002).

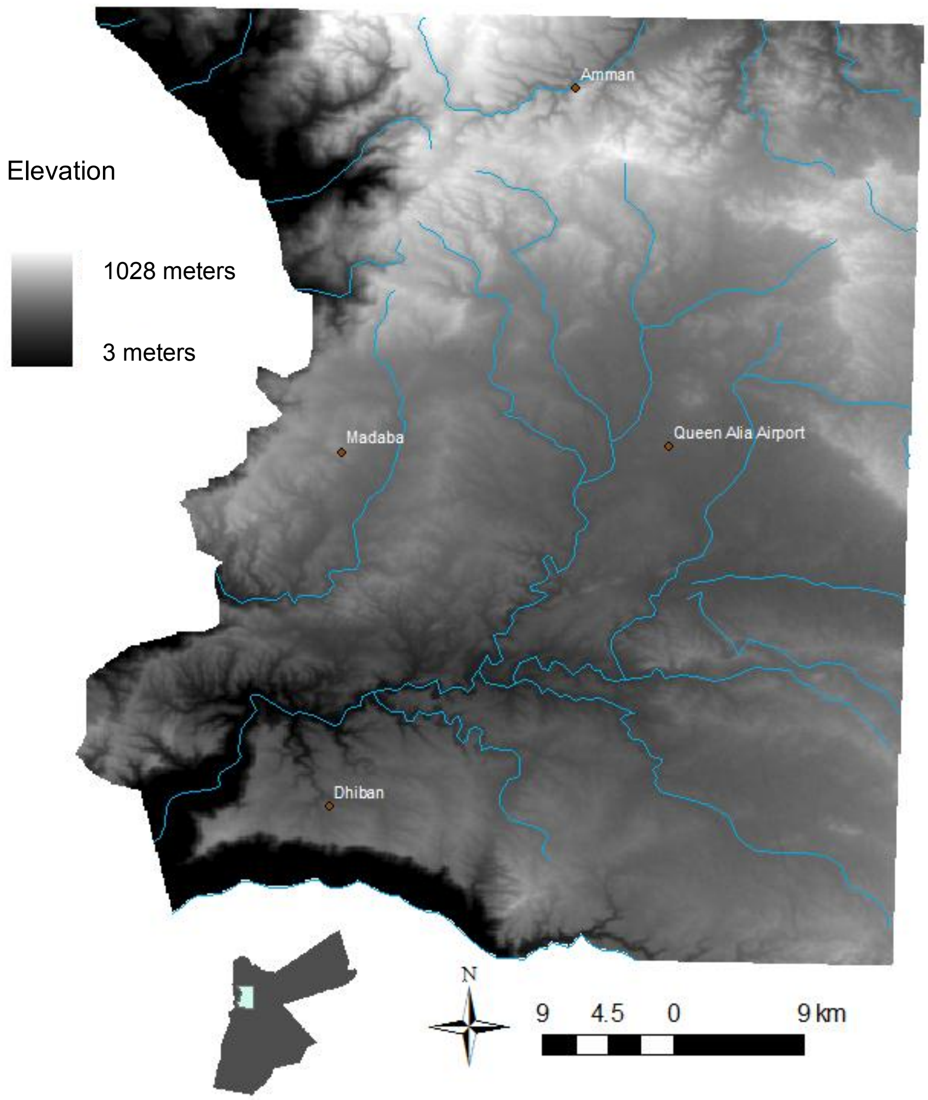



**Figure 2.5:** Relief map of the study area showing the various wadis associated with the Madaba Plain. Note the location of the major cities.

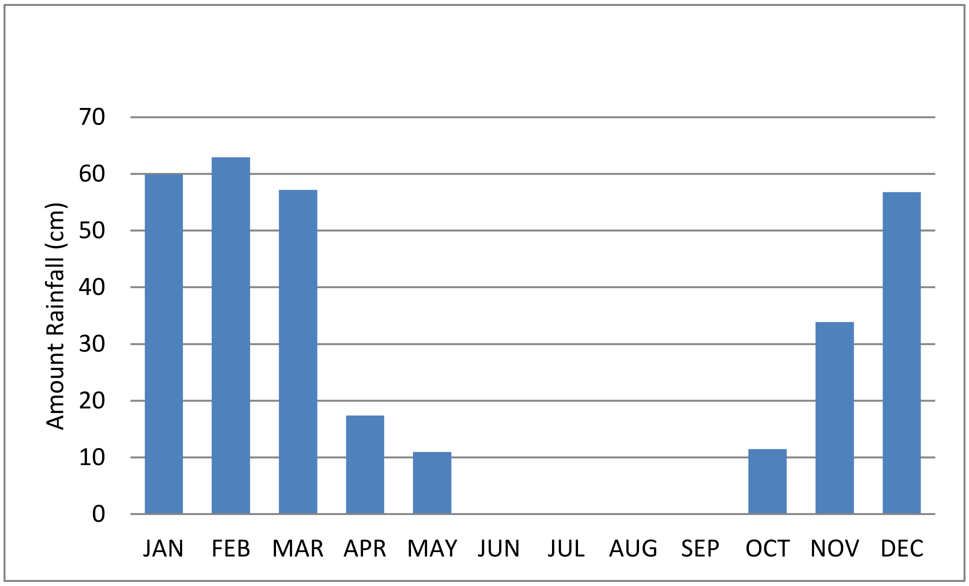



**Figure 2.6:** Average rainfall totals for Madaba Plain 1942-1996 (data obtained from MWI 2007).

Geologically, this area is located on the Nubain-Arabian shield, being underlain by sedimentary rocks ranging from 4-12 km in thickness (Schnurrenberger 1997). This entire area also contains exposed marine carbonates with minor cherty components. Underlying these carbonates are sandstones from the Mesozoic and Paleozoic , as well as an intrusive rock basement (granites, gabbro) from the Precambrian (figure 2.4 and 2.7). The oldest geologic unit exposed at the surface is the Fuheis Formation, which is a nodular limestone with traces of chert and marl that ranges in depth between 55-90 m (Alsharhan and Nairn 1997). This formation is essential to the region, both in agricultural and economic terms, in that it weathers to form fertile soils and is also used as a source of cement (Masri 1963). Groundwater in the study area is provided by two main aquifer complexes, the Hummar Formation aquifer system, composed of white to creamy limestone and gray dolomitic limestone (dense, highly fractured, and fossiliferous) measuring between 40-60 m in thickness.

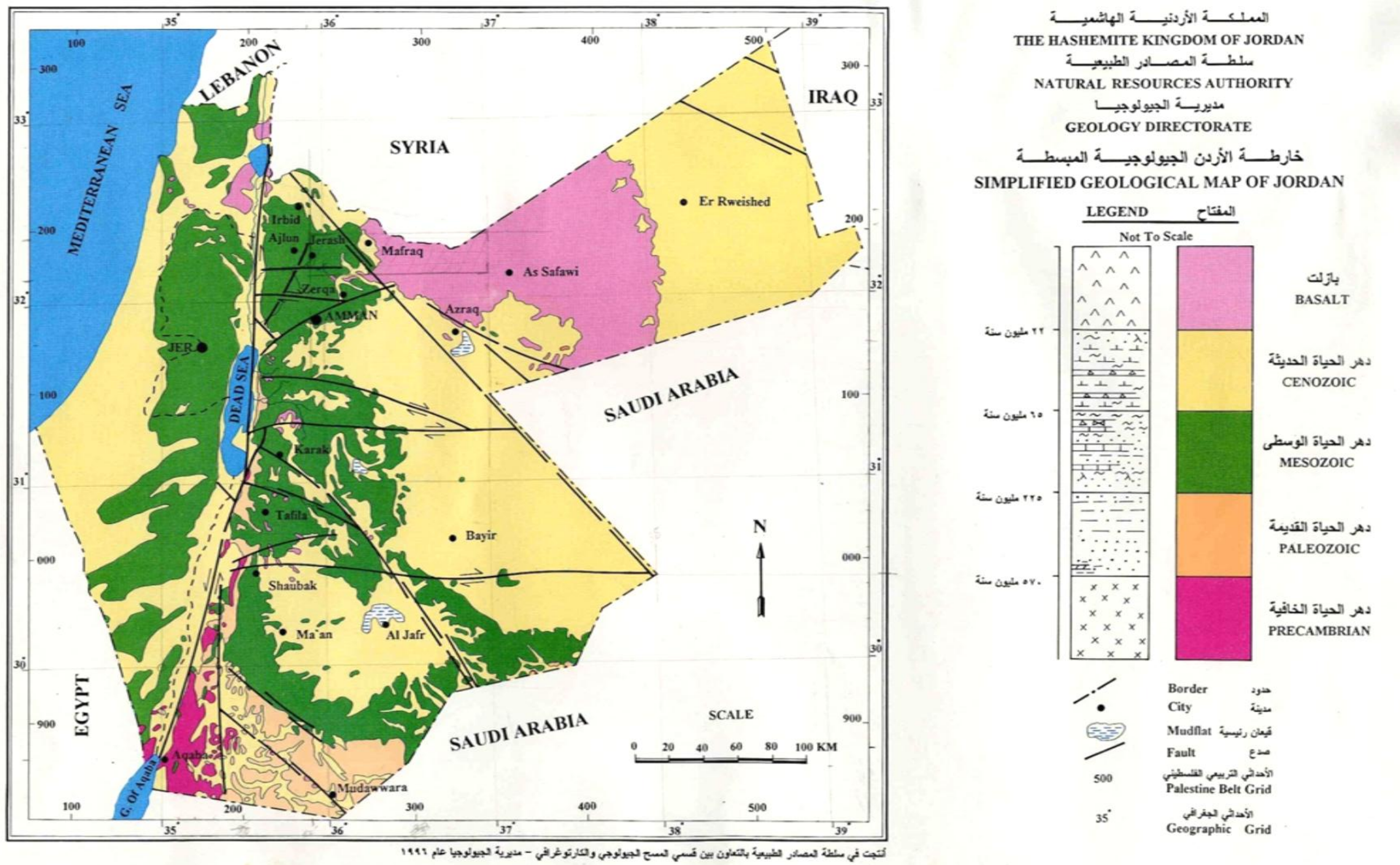



**Figure 2.7**: Geologic map of Jordan measured by time scale.

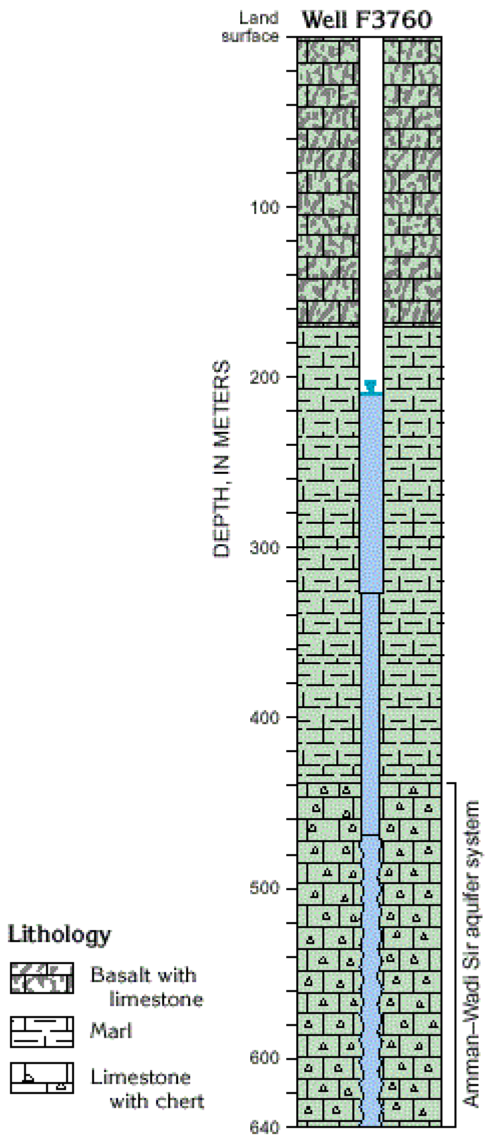



**Figure 2.8:** Stratigraphy of Amman-Wadi Sir system (http://exact-me.org/overview/toc.htm 2009)

The other aquifer component is the Amman-Wadi Sir aquifer (figures 2.8, 2.9) system that is composed of two complexes. The Wadi-Sir Formation measures between 90-100m thick and consists of gray crystalline limestone (Masri 1963) and is overlaid by the Amman Formation, which measures between 100-120 m (Schnurrenberger 1997). It is composed of brown chert and light grey fossiliferous limestone (Masri 1963). The main source of recharge to these aquifers is precipitation.

Soils (figure 2.10) in the area are classified as either Red Mediterranean Soils (Moorman 1959) or Terra Rosa Soils (Lacelle 1986). These light- to dark-red soils are believed to have formed during the Quaternary during periods of high precipitation, forming on the limestone bedrock where precipitation ranged from 250-500mm. The red coloring of the soil is due to the heaematite content, which is formed by a long and intensive weathering process (Bronger and Sedov 2003). The high clay content (60-70%) allows for a deep cracking of the surface during dry conditions. This lets precipitation infiltrate deep into the ground and allows for retention of moisture throughout the year (Schnerrenberger 1997).

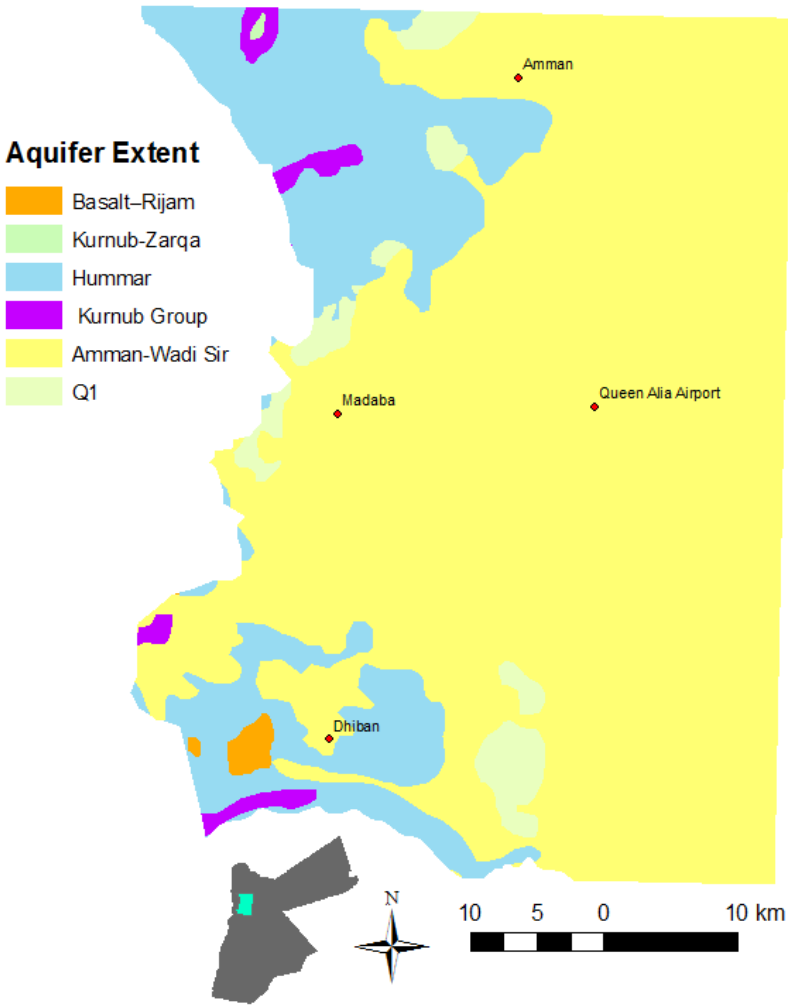



**Figure 2.9:** Aquifer extents in the study area
(taken from http://exact-me.org/overview/toc.htm 2009)

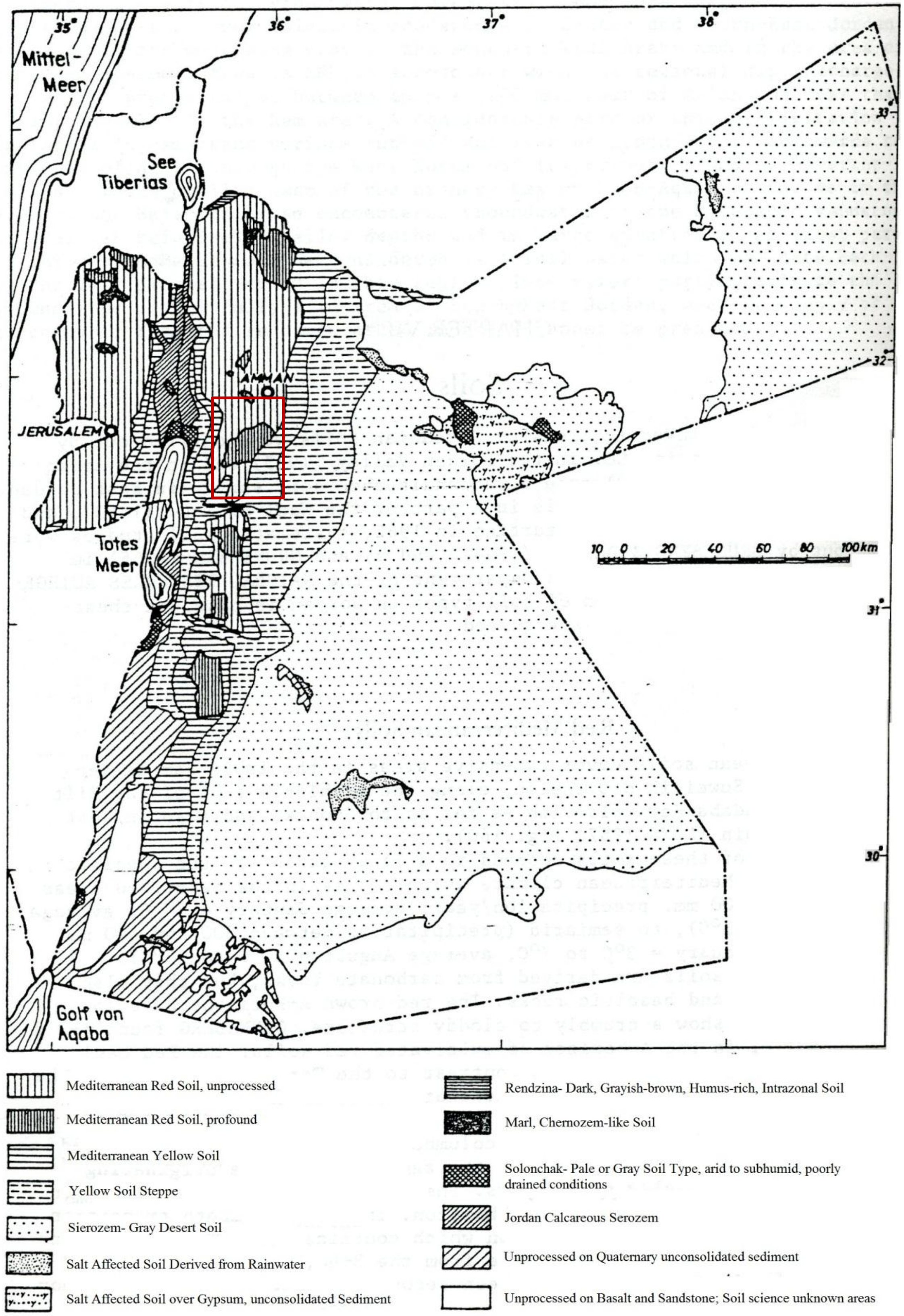



**Figure 2.10:** Soils of Jordan (taken from Bender 1974).

**Climate**

Contemporary issues of global warming are a great cause for concern for the region due to the high population growth rates projected over the next decade (Table 2.1). Although precipitation might not be affected, a predicted increase in mean temperature of .8-2.1$^{o}$ C could dramatically impact the water balance (table 2.2) and available soil resources (Bou-Zeid and El-Fadel 2002). This would happen in the form of evapotranspiration, evapotranspiration deficits, surpluses and moisture deficits. These effects may lead to dying of soil surface as well as a decrease in cloud density, which in turn would lead to even higher temperatures (Garnaut 2008). Another consequence of an increase in temperature would be a loss in recharge to water aquifers. Soil moisture will decrease, due primarily to increased evapotranspiration, creating an increase in water demand and possible changes in the vegetation of the non-irrigated regions (Van Dam 1999). Projected decreases of 15% in water availability and an increase of 6% in agricultural demand by 2020 would cause a multitude of problems in the region (Bou-Zeid and El-Fadel 2002). Ultimately, these factors may be cause for civil unrest as supply of agricultural products would not be able to keep up with demand due to diminished water supplies and arable land.

**Table 2.1:** Population growth rates of countries in the Levant

| ***Country*** | ***Growth %*** | ***World Rank*** |
|---|---|---|
| Gaza Strip | 3.35 | 5 |
| Israel | 1.67 | 79 |
| Jordan | 2.26 | 42 |
| Lebanon | 1.11 | 121 |
| Syria | 2.13 | 50 |
| West Bank | 2.18 | 45 |

(CIA 2009)

Already depleted aquifer levels would be stressed even more causing more difficulty on the storage and implementation of groundwater resources. In turn, this will cause an increase in the energy needed to pump water from aquifers. With energy costs rising globally, water prices would have to follow which would cause a downturn of the Jordanian economy.

| **Table 2.2:** Some Impacts on water resources expected with climate change | | |
|---|---|---|
| ***Resources*** | ***Major impacted components*** | ***Potential effects*** |
| | | |
| **Hydrologic Resources** | Precipitation | Soil moisture changes |
| | Evaporation | Reduced groundwater recharge |
| | Transpiration | Water shortages or surpluses |
| | Runoff | Dam failure due to floods |
| | Recharge | Dam storage loss due to sedimentation |
| | | |
| **Water quality** | Water temperature | changes in chemical quality |
| | Water Salinity | changes in biological quality |
| | Pollutant concentrations | Changes in thermal quality |
| | Fauna and flora | |
| | | |
| **Aquatic systems** | Streamflows | Droughts of floods |
| | Erosion and sedimentation | Dam failure due to floods |
| | Water levels in surface water bodies | Dam storage loss due to sedimentation |
| | Water leves in aquifers | |
| | Water fluxes in subsurface | |
| | | |
| **Water supply** | Water demand per capita | Water demand increase beyond projected levels |
| | Agricultural water demand | |
| | | |
| **Water management systems** | Streamflows | Reduced water supply |
| | Water levels in surface water bodies | Changing loads on water treatment systems |
| | Water levels in aquifers | Changing hydropower production potential |
| Taken from Bou-Zeid and El-Fadel 2002 | | |

Goudie (2000) discusses the high demand for water in Saudia Arabia, where water usage went from 3.4 MCM to 12 MCM in the span of 10 years. A number of reasons are responsible for this phenomenon which is indicative of the region as a whole: First, the increased global temperatures cause a higher rate of evaporation. Second, the increasing population rates result in greater water usage. As the population increases, demand for water increases. A number of sectors would be effected. The agricultural sector would need water in order to produce more food for the growing population. The municipal sector would need more water for drinking, cooking, and hygiene purposes, as well as landscaping that takes place in order to beautify areas. The industrial sector likewise would need increases in water supply to keep up production of goods for an increased population. Finally, expanding agriculture is the most water intensive usage in such a dry climate. Goudie (2000) estimates that a 42% decrease of groundwater resources will take place by 2025. It is important to record and map these trends in order to create an adaptive policy in regards to conservation of aquifer resources.

Throughout the region, the effect of climate change on regional water resources may be exhibited in a number of ways. Yechieli (2000) demonstrates the effects of high evaporation on the Dead Sea and surrounding water sources. From 1970 to 1990, the water level of the Dead Sea has declined at an average rate of 60 cm/yr, until 1990, when it accelerated to 100 cm/yr. This is important because ground water resources in the region are governed by Dead Sea levels. During this time of decline in Dead Sea levels there has been a corresponding drop in groundwater levels. Another effect of the decrease in Dead Sea level is the effect on fresh water chemistry. Residual salts left by receding water levels contaminate freshwater that drains into previously occupied areas.

Along with climate change, desertification is an ancillary form of environmental decay. The basic process of desertification starts with deforestation due to human activities (agriculture). This subsequently leads to accelerated surface runoff and the erosion, removal and/or salinization of fertile soils (figure 2.11) that includes both the seeds of the plant being harvested, and organic nutrients needed to sustain agriculture (Bainbridge 2007). Lack of vegetation leads to a low infiltration rate and decreases to virtually zero for very dry regimes (El-Baz and Hassan 1986). Throughout history, many areas of the world have been degraded to the point of being inhospitable or have seen populations reduced to a minimum.

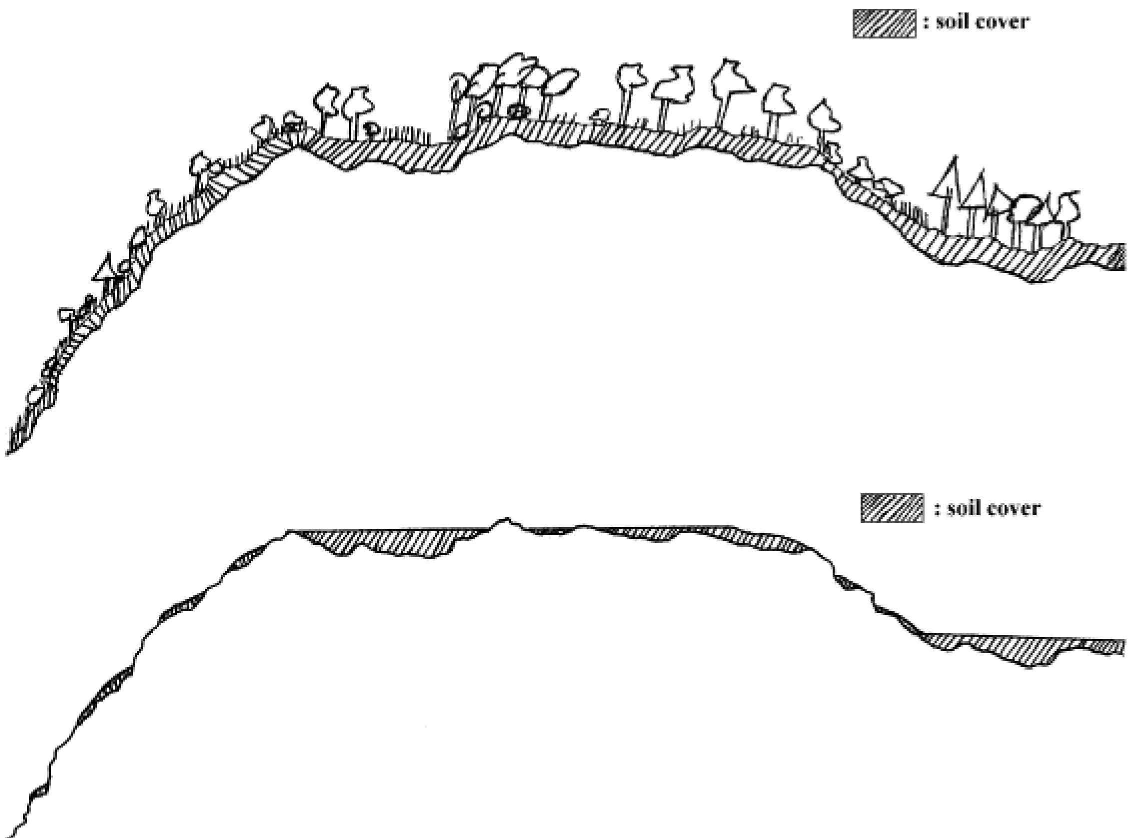



**Figure 2.11:** Generalized schematic showing soil coverage before and after deforestation takes place (taken from Schmidt et al. 2006)

This phenomena has taken place in the village of Dhiban, a 6000 year old settlement that once supported approximately 4000 people. This village is located close to the southern border of the study area, near Wadi Mujib. Intensive agriculture and the subsequent salinization of the soils has caused desertification. Contemporarily, the village is still active, but to a much lesser extent. Due to the environmental pressures, the village only supports 240 people (Abbas 1989).

On average, the wheat harvest from this area is approximately 300 kg/ha, however in drought years, the total drops to approximately 40 kg/ha (Abbas 1989).

Although there are proven theories that human activities degrade soil quality, Lucke et al.'s study (2007) in the Decapolis region in Jordan proposes that climate change and extreme rainfall events have a higher impact on soil degradation than agricultural activities such as grazing. These types of weather events have caused a number of documented landslides as well as a strongly reduced vegetation cover. Further supporting this claim is the evidence that points to erosion of the Terra Rosa soils taking place during the end of the last ice age and during the Youger Dryas and came to an end during the beginning of the agricultural revolution. There is some evidence that centuries of plowing has caused once undulating landscape to become relatively flat, but maintain a heterogeneous soil signature (Schmidt et al. 2006).

Goudie (2000), Mckinney et al. (2003) and Brooks (1997) have all discussed the ramifications of high evaporation rates in arid environments, especially pertaining to deforestation of land for agricultural or industrial purpose and specifically of the effects of irrigation. As irrigated water is evaporated, it leaves behind a concentrated form of salts. As a result, a "salting of the earth" effect is initiated that renders the plot of land non arable (Abbas 1989).

One case study (Abbas 1989) where this phenomena occured is the town of Wadi Dhuleil, located approximately 20 km east of Amman. It was originally designated as a refugee camp, but in addition Bedouins were forced to settle there. Due to the location (the area was extremely arid to begin with) the town relied on groundwater pumping to survive. Investors from Amman bought up much of the land, then rented it out for agricultural purposes. The area was eventually overused and irrigated to the point that salinization occurred, and the desert retook the area.

The aforementioned case studies in climate demonstrate the hazards associated with climate change and unsustainable agriculture that have already taken place within Jordan. These hazards are currently transpiring and need to be mitigated, due to the limited availability of both arable land and ground water resources. Failure to limit these hazards will put increased pressure on resources as populations grow and may be a cause for civil unrest, which may spread to the region as a whole.

# Chapter 3: Literature Review

## Historical Climate Change

In the Middle East, the climate of the last glaciation (10,000-50,000 bp) varied more than that of today. Butzer (1958) describes the climate as being much more humid with woodlands along the Mediterranean coast in the Levant area, and a steppe environment along the desert trade routes of Northern Libya and extending to the Arabian Penninsula. During this time, world sea level was reduced by approximately 300 ft, however levels of non-inlet lakes increased. The Dead sea had an increase of approximately 650 ft, which was a direct result of lower evaporation rates in the region. The snow lines of mountain ranges in the region were lowered by an average of 2500 ft (Butzer 1958). Floral and faunal remains in the region indicate animals that were not suited for arid conditions. The effects on rivers were also notable, in that rivers carried more water and lasted for a longer time then present.

Bar-Matthews et. al. (1996) seem to confirm Butzer‟s assessment as they found that $^{18}O$ and $^{13}C$ levels in speleothems correspond to a modest amount of precipitation on the order of 300-450 mm for the period of 25,000 to 17,000 yr B.P. On the landscape, the decrease of temperatures during this time period, lowered tree lines by approximately 2,500 ft, which in turn caused high altitude areas to be inhospitable (Butzer 1958). From 17,000-10,000 yr B.P., Bar-Matthews et. al. (1997) contend that warming occurred bringing with it a gradual increase in precipitation. Mount Lebanon was covered with temperate species of foliage such s oak, beech and elm. There was marked moisture along the northern desert trade belts that transformed the vegetation.

There are also faunal remains of extinct forms of rhinoceros, hippopotamus, horses and other ungulates found in the Levant. Levalloisian tools arise in the Levant at dates of approximately 30,000 B.C. that suggests hunter gatherer type societies during this time (Butzer 1957). These types of societies tend to have a minimal impact on the environment, because they followed resources, as opposed to settling in a specific area and consuming all resources at that point.

Moore and Hillman"s (1992) study discusses the Younger Dryas" impact on the region using archaeological evidence to support their theory on climate change. Approximately 15000 years ago, the climate began warming up until approximately 11000 years ago, with the advent of the Younger Dryas. Proxy data such as pollen and other archaeological records indicate a shift to the Younger Dryas. This was a worldwide phenomenon that cooled the earth down to near glacial conditions. In the Middle East, the climate turned arid as explained by Moore and Hillman. This time period is divided into 3 sequences starting from 11,500-11,000 BP. During this sequence, the inhabitants gathered plant foods from 3 vegetation zones: the floodplain, the steppe, and the forest. The archaeological record at Abu Hureyra (located in northern Syria on the Euphrates) indicated that inhabitant"s diets consisted of many fruits, such as plums and pears, as well as cereals such as wild einkorn wheat that are prevalent in humid environments. At the beginning of the Younger Dryas, the researchers observed a marked decrease in the fruits eaten, and an increase in cereals. This form of nourishment was extensive until approximately 11000-10400 years ago. The theory proposed by Moor and Hillman is that the forest began to die off and the cost to get to the forest rose. At approximately 10,400 to approximately 10,000, inhabitants of Moore"s study show that there was a massive decline in the use of cereals. Instead, they subsisted on "fall back" foods such as small seeded legumes.

Later near east climate is described by Rossignol-Strick (1999) in a study done on pollen samples obtained from sapropel (sediment saturated with organic matter). The dates studied range between 9000-6000 BP. Marine pollen records, where preservation of pollen is consistent, correspond to terrestrial records. One example the author gives is variation of Quercus (oak) pollen that shows the same pattern as marine sites. The data suggests that the early Holocene was the wettest and warmest period of the post glacial with extremely mild winters. The author also contends that precipitation values in the region during this time were 800-1200 mm annually. This wet period lasted until approximately 7000-5000 bp, where Thomas (1997) observes that the present state of aridity in the region starts.

Bartov et al. (2003) reconstructs levels of Lake Lisan (paleo Dead Sea) to obtain climate records for the immediate locales. The time period studied is 55,000-17,000 bp at 1000 year resolution using C14 and U-TH dating methods at which time a Heinrich event occurred. Heinrich events are the phenomena of freshwater (through glaciers and icebergs) being introduced into the oceans that gradually change the salinity levels (Stein et al. 2010). These changes have a cooling effect on ocean water and generally lead to a cooling of the earth‟s climate. Bartov et al. (2003) contend that although the Heinrich events led to a decrease in evaporation and high lake levels, drought was also widespread due to lack of precipitation.

McCorriston (1991) contends that climate in the Middle East was seasonal towards the end of the Pleistocene ( approximately 10,000 bp) to the point that there was a depletion of natural resources. This seasonal variability is partly responsible for the rise of a more sedentary lifestyle of peoples of the area. Weiss and Bradley (2001) further examine the role of climate variability on human settlement patterns. The lack of precipitation caused the indigenous peoples of the region to change from hunter gatherer types of societies to sedentary societies, which required more intensive labor at approximately 12,000 BCE. After, the Younger Dryas societies were forced from this area to adopt permanent settlement and cultivation (Bar-Yosef 1996, 2000). While these practices are needed for a population, they are detrimental to soil and water quality.

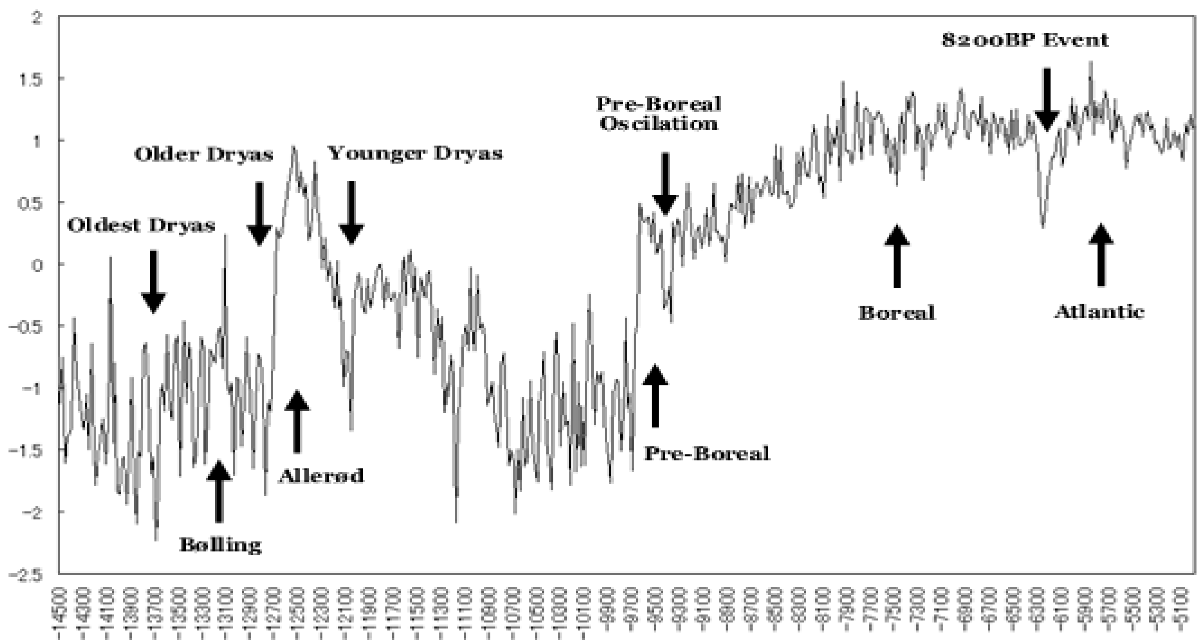



**Figure 3.1:** the standardized temperature fluctuation in the transition from Pleistocene to Holocene restored from delta 18O data (taken from NOAA 1997) Horizontal axis denotes years B.P.

At approximately 6400 BCE, the climate changed in the Levant and led to a collapse of agricultural villages and a rise in urban centers (Gasse 2000). Gorring-Morris and Belfer-Cohen (1998) concluded that a 200 year-old drought took place around this time that led to the collapse of agricultural villages. The beginning of the $6^{th}$ millennium BCE brought the return of moister conditions which led to irrigated agriculture (Issar 1995). Evidence of irrigated agriculture is well known from the Uruk society at approximately 3,500 BCE, where it lasted 300-500 years and collapsed due to severe droughts (Bar-Mathews et al. 1999). Wetter periods occurred again until approximately 2,300 BCE, where regionally scaled societal collapses took place due to drought (Harlan 1985). Frumkin et al. (1991) proposes that aridity increased in the region from 2400 B.C.E to 2000 B.C.E based on the 100m decrease of the Dead Sea during that time. Other studies from this time period in the region confirm this finding by demonstrating that Mediterranean sea level increases took place during this time (Rabin and Galili 1985) and that soil moisture had decreased due to higher evaporation (Weiss et al. 1993).

Lucke et al. (2007) propose three fundamental explanations as to why settlements in the Mediterranean region may have been abandoned: a) population growth or conquest that caused an over exploitation of the land b) natural climate variations that may have caused drought or bad harvests and c) political or economic developments . Schmidt et al. (2006) maintain that devastating human induced erosion did not take place from the time period of the Romans and Byzantines due to the amount of archaeological evidence that is present and would have been removed along with any eroded soil.

Many previous studies have been conducted on the collapse of Bronze Age societies in the Levant. Rosen (1997) believes that the climate was a factor, but not the only thing that led to a collapse. During the Roman period of occupation, the Middle East was very humid. Issar and Yakir (1997) point to the Masada being self-sufficient and able to grow their own crops during the Roman siege of the plateau. During this same time period, Nabateans from Transjordan began settlements in the Negev based on irrigated agriculture (Evenari et al. 1971). Issar (1995) states that there is a relationship between climactic events and people. The example cited is that the warmest and driest periods coincide with invasions of agricultural lands, while the coolest wettest periods are associated with agriculture and the rise of cities.

Throughout history, there is evidence that humans have had an impact on their surrounding environments. Redman (1999) has shown the effects on Neolithic sites in Jordan, specifically at the site of Ain Ghazel. The homes there used plaster on the walls and in some cases were replastered annually. The local population relied on goat herds, which added to the problem. In order to make plaster, the villagers would cut down the surrounding forest to use as fuel. Although the forest attempted to regenerate, the goats would feed on the saplings. This led to less and less forested land. Eventually the land degraded so greatly that no trees were able to regenerate and the settlement was subsequently abandoned. In the $20^{th}$ century, the number of livestock in the region has increased 5-fold putting additional pressure on natural resources (Mainguet 1994).

Many people attribute the Levant‟s arid environment partly due to historic deforestation events. Mikesell (1969) discusses ancient Egypt and the Roman‟s role in the deforestation of Mount Lebanon. The Egyptians desired Cyprus trees from the area to make boats and sarcophagi and had a heavy trade for lumber with the Phoenicians. Romans required trees from this area for military purposes.

These studies demonstrate two points about the Levant region. The first is that historically, the region was very humid. This is an important point to consider because aquifer recharge levels will likely not reach what they once were as global warming continues for reasons that were previously discussed. The second point is that historically, human interaction with the environment has caused substantial degradation in the region. Deforestation, un-efficient irrigation, and livestock over grazing has had a negative impact on a number of the aforementioned sites, to the point where desertification caused these sites to become unsustainable and mass migrations took place (Lowdermilk 1944, Hillel 1991).

**Land Laws and Taxation**

Although the Ottomans began their expansion in 1299, Ottoman taxation in the region began in 1516 (Lancaster 1999) once the Ottoman empire had grown and conquered the Levant region. During this time, the Ottomans surveyed and divided the land into a number of separate classes under the categories of: state domain, *timars*, and privately owned lands. The *timars* were a feudal type system in which the Ottomans gave the local nobles and tribal leaders land for their cooperation. Taxes from these lands were collected by *Sipahis* (military officers) who would also collect their salaries from village surplus (Aswad 1971). In the 17th Century there was a shift away from this type of tax collection to a system called *iltizam*. In the new system the Ottomans auctioned off the right to collect taxes to local aristocrats. An agreed upon percentage of the taxes would go to the central authority and the difference would remain with the local. The issue that arose from this type of system was that the Ottoman‟s began losing influence as the locals became more wealthy and powerful (Fischbach 2000). In many cases these tax farms became inherited.

Prior to direct Ottoman rule, there was a pattern of land ownership called *Musha*, in which there was collective ownership of land, instead of individual ownership of plots. Inhabitants of a region would divide the land among themselves in a 2-3 year rotation (Keyder and Tabak 1991). Aswad (1971) describes the *Musha* as a nucleated core village, which is characterized by as having a strong lineage of sharecroppers. Many times, the redistribution of land between villagers occurred by drawing out of a hat (Aswad 1971). In some cases village elders or representatives would decide who received particular plots (Fischbach 2000).

There were several ways to partition the land to the villagers. The first was known as *dhukur* (Fischbach 2000). In this system shares were divided equally between all males in the village.  The second method was known as *faddan*, in which shares were divided up between owners of plow animals.  Finally there is the system of *hissa*, where shares were divided according to a fixed number.  Due to the fixed system, problems occurred where a family had to divide a plot into fractions so each family member could get revenue.

The net result of these systems is that each shareholder would work a long, thin strip of land in various areas of village owned land (some more fertile than others).  As more and more inheritance claims were founded, these strips would become smaller, occasionally to the point where it was not efficient to cultivate the land (Fischbach 2000).  In cases like this, land was either jointly cultivated, or rented out.  The proceeds were then divided between the villagers proportionate to how much land each owned.

There are conflicting theories as to why the *Musha* system developed.  Warriner (1948) cites the lack of individualism prevalent in Arab culture as the cause.  Granott‟s (1952) believes that the *Musha* system is a remnant of nomadic communalism. Finally, Firestone‟s (1981) suggestion is that the formation of *Musha* lands was directly related to taxation policies, more so then any other factor.

The period of the *Tanzimat* reforms from 1839-1876, was brought along by a number of factors.  The loss of control of outlying provinces as well as intrusion of European political, military and economical influences occurred then.  Ottoman authority was imposed by curbing local leaders authority as well as imposing a western style bureaucracy and controlling hajj (pilgrimage) routes that had been established (Fischback 2000).

Direct Ottoman rule over the Transjordan region occurred in 1851 when a sub-governorate was founded in Ajlun (Fischback 2000).  The administrative center had far reaching authority and answered to the Governorate of Damascus.  The Ajlun Governorate facilitated the legislation of the Land Code of 1858 to be enacted and enforced throughout the region. The purpose of the law was twofold; the law required that land be registered with, and taxed by the Ottoman Empire. The aim was to not only increase tax revenue, but also curb the power of the prominent locals within the Ottoman Empire.

The Land Code divided the empires land into 5 legal classifications. The first classification, *Milk*, is private land where the landowner possesses undisputed ownership in the form of a title called a *raqaba* (Fischbach 2000). *Milk* land is further divided into 3 categories: land built up in, and the outskirts of towns and villages; *mulkname*-land that was formerly owned by the empire, but later transferred to a private owner; and two older forms of private land called *ushriyya* and *kharajiyya*.

The second classification is called the *Miri*, which is state controlled land. Rights were given out to people for use of the land if they payed a fee called a *tapu* (Fischbach 2000). These rights were inheritable and could be bought and sold with Ottoman permission. The state also reserved the right to revoke any agreements. This would cause the land to become *mahlul* (dissolved) status until the land was either reallocated or outright sold into *Miri* status.

The third classification ordained by the Land Code is the *waqf* (Lancaster 1999). *Waqf*s were an endowment of land for a charitable or religious public cause (Keyder and Tabak 1991, Fischbach 2000). In many cases there was a religious shrine located on *waqf* declared land that the state taxed a percentage for upkeep. The name of this type of land is derived from the Arabic word "stop" or "*qaf*". Under this category the title of the land was stopped and the land itself could not be sold or altered into subdivisions (Fischbach 2000). *Miri* lands could not be endowed the *waqf* status because the state owned the lands. However, with permission and a some stipulations, there were three ways *Miri* lands could be considered charitable. The first was to use the taxes on the land for a charitable purpose, while allowing the tenant to keep the income produced on that land. The second was to allow the right of usufructure be used for charity, while taxing the tenant normally. Finally, both the taxes and the usufructure purposes are both endowed to charity.

The fourth land classification from the Land Code is called the *matruka* (Fischbach 2000). These lands are non-arable lands that have been set aside for public good. Lands devoted to an entire town or village that are used for markets, pastures, or forested areas used for firewood are considered *matruka*.

Finally, the *mawat* lands are the plots that were not used for anything (Fischbach 2000). The word is derived from the Arabic word for dead or "*maht*". These areas could not be used for agriculture and were far away from any towns or villages. However, it was possible to revive a *mawat* parcel for purposes of agriculture. If this was done, the *tapu* fee would be waived and the land would be reclassified as *Miri*. There were a number of stipulations required to be met before the state would provide a permit: one was that no slaves could work the land, and another was that the share croppers would get a percentage of the crop. The percentage was determined by the state (Keyder and Tabak 1991).

One of the net results of the Ottoman land laws was the formation of a landowner class, called the *effendis*. Literally translated as "sirs", the *effendi* class usually came from Palestine and Syria, and invested agriculture (Fischbach 2001). They were largely either Christian Arabs, or non-Arab Muslims (Kurds, Turks) that were employed to some extent by the Ottomans.

The *effendis* main acquisition of land was through loan defaults by borrowers. There were a number of types of loans that pertained to specific land classifications. The first is called a *rahn*, and was applied to *Milk* land. The „*rahn*‟ was a pure mortgage (Fischbach 2000), in which the land was assured as collateral for the loan. The land remained with the borrower unless the loan was defaulted on. *Effendis* created another loan for *Miri* lands called *faragh bi'l-wafa* (Fischbach 2000). This systems was more complex then the *rahn* system, due to the fact that *Miri* lands could not be sold to third parties. The system also gave lenders control immediate control of the land for the duration of the loan. This resulted into a twofold effect where lenders received a percentage of the crop revenue, and in doing so, hindered the ability of the borrower to pay the loan back. Because land could not be sold to third parties, a government agent with the authority to sell land assets was assigned to facilitate the sale to the lender (Fischbach 2000).

As more and more cultivators became indebted to *effendis*, the Ottomans took a number of steps to relieve pressure on borrowers. In 1866, they established a bank from taxpayer money to help ease the use of *effendi* lenders. Later, in 1887, the government set out to regulate the interest rates on the *faragh bi'l-wafa* loan, by setting the maximum at 9% and standardizing contracts (Fischbach 2000). Finally, in 1913, the loan was banned from use.

With the departure of the Ottomans after World War I, the fledgling nation of Transjordan attempted to tax cultivators in the framework of the old Ottoman laws. However complications arose due to the fact that old Ottoman records were incomplete due to the fact that the Ottomans took or destroyed many records as they retreated from the region (Fischbach 2000). Taxation was further compounded by a refusal of many landowners to register their land. In 1921, the government resorted to using tax farmers, much like the ottomans, to collect taxes back until 1918. As the government became more intrusive, more resistance was exhibited. This came to a head in the form of an uprising in the Kura district of Ajlun. Because of the complications, the government repealed any taxes that were owed between 1918 and 1920.

Another aspect of colonial rule comes during the formative years of Transjordan comes from Fischbach (2001). Of particular note was the British handling of the *Waqf* of Abi Ubayda, who was a companion of the prophet Mohammad. Ottoman authorities had established this *Waqf*, and had allowed a certain percentage of revenue to be paid to the landowner for upkeep of the site. A complication arose when a family that had been in exile returned to the area and laid claim on the land. Using mainly the *Tanzimat* laws, the British magistrate ruled against the exiled family, citing a stronger claim to the *waqf* by that current landowner.

Due to the loss of tax revenue, British replaced the *Tapu* system with a colonial based cadastral system. Although the British thought of Ottoman system as antiquated, "the land code of 1858 and the civil code of 1869 introduced a state-guaranteed land registry which did not exist in Britain at that time" (Home 2006).

The British policy consisted of 2 key points that Fischbach (2000) discusses. The first is that all land was owned by someone. The second was that land should maximize productivity. This often times clashed with the view of indigenous populations, and especially in the cases where *Musha* was being practiced.

However the change to privatization of land holdings was to go forward, using a number of land management techniques. The British consulted with Sir Ernest MacLeod Dowson, who made a number of suggestions pertaining to the Levant region (Home 2006). First, he proposed that the Torrens system be implemented. This allowed for an alternative in registration when there was a lack of definitive proof of land ownership. Torrens proposed to register the units of land instead of the actual owners, but noted who the owners were (Fischbach 2000). This allowed for determining titles for specific plots of land. Another proposal by Dowson was to gather data by using surveys and cadastral mapping techniques . With the switch to a cadastral system, the authorities removed the *Musha* category (Lancaster 1999) as plots were assigned individual owners. The British thought that a community based tenure system was inefficient and sought to maximize productivity by partitioning the *Musha*s into individually owned plots (Fischbach 2000). Home (2006) contends:

> "The state secured private property rights at the expense of collective village rights, based upon the assumption that all usable land had to be owned by someone, in order to maximize revenues and productivity. Thus the state became the regulator of property transfers rather than the collective memory of individual communities."

In 1927 the Land Demarcation and Valuation Law was passed, and a fiscal survey was issued with the purpose of mapping village boundaries and placing a value on the various plots of agricultural land (Fischbach 2000). The value of agricultural land was based upon fertility, crop return estimates, and contemporary crop prices.

In 1929, the government tried to encourage land registration by passing the Land Registry Fees Amendment Law which waived registration fees. Along with this, they also implemented harsh punishments to any land transactions carried out privately, by declaring those transactions null (Fischbach 2000). In 1933, two laws, the Land Tax Law, and the Land Settlement Law were established. The Land Tax law was created to increase tax revenue for the state, but ultimately proved to be costly and unpopular (Fischbach 2000). The Land Settlement law created a legal council outside of state law, that gave this committee sweeping power to in areas that are being settled. Fischbach (2000) notes that the aim of the law was to find the "right" owner to the land, and not necessarily the legal owner. Land settlement in Amman started in 1934 and lasted until 1952. Further south in Madaba, settlement started in 1939 and lasted until 1949. During this time period, a record number of court cases were brought to the land settlement court (Fischbach 2000).

The State Lands Law of 1928, as well as the Disposal of State Lands Law in 1929 allowed the executive council to sell state lands(Fischbach. Lands that were sold in this way were designated *Miri* status. State land was usually sold to tenants that had been previously farming those particular plots. The tenants were not allowed to sell this land until the all payment was made. However there were still cases in which land that had yet to be surveyed and categorized in the new system was considered state or tribal land. In 1972, tribal claim over land was abandoned, and all unregistered land became state land (Lancaster 1999).

The expected results of the British land program were to obtain higher revenue, both in the form of taxes as well as crop yield. Crop yield was erratic after the implementation of these laws (Table 3.1).

**Table 3.1:** Agricultural Production, 1927-1953 (Tons)

| ***Year*** | ***Wheat*** | ***Barley*** | ***All Grain*** | ***Fruit*** |
|---|---|---|---|---|
| 1927 | 35,000 | 12,000 | N/A | N/A |
| 1932 | 41,700 | 10,000 | N/A | N/A |
| 1936 | 40,800 | 16,800 | N/A | N/A |
| 1937 | 113,000 | 53,000 | 117,300 | N/A |
| 1938 | 85,100 | 45,000 | 139,320 | N/A |
| 1939 | 168,400 | 98,300 | 271,040 | N/A |
| 1940 | 171,000 | 58,000 | 234,070 | N/A |
| 1941 | 71,000 | 31,000 | 103,710 | N/A |
| 1942 | 113,000 | 51,000 | 169,600 | N/A |
| 1943 | 100,000 | 55,000 | 161,350 | N/A |
| 1949-1950 | 106,031 | 41,406 | 184,250 | 16,546 |
| 1953 | 94,032 | 29,847 | 150,698 | 66,143 |
| | Source: Fischbach 2000, pg. 127 | | | |

During this same time period, tax revenue increased only by 12.2 percent, which was not enough to wean the Transjordan off of British Aid (Fischbach 2000). One reason was the Tax Remission Law of 1933 which took into account any environmental factors, such as precipitation, pertaining to crop yield. In the cases of severe water shortages, taxes were decreased by 50 to upwards of 100% of what was owed. Settlement fees were also imposed, but did not make up the cost of the actual settlement process (Fischbach 2000).

The cadastral based systems effect was to keep most of the old Ottoman categories relevant, while at the same time, giving more authority to the central government. As populations rose and villages expanded, *Miri* land became *Milk* or privately owned (Fischbach 2000). This has far reaching effects as inheritance was based on religious law, which gave women half as much as men. As urban sprawl developed, women lost more land relative to what they would have retained under the *Miri* system. At the same time, the state effectively cut down on the number of *waqf* declared land, and seized what was left. One of the more important aspects of partitioning of *Musha* lands was the unforeseen side effects that were detrimental to the physical environment. Plot sizes became more fragmented as population increased and inheritance laws took effect (Fischbach 2000, Lancaster 1999). Instead of dividing rent capital for the whole plot, individual owners were now forced to collect for a fragmented section. This caused individuals to physically divide the land into individual plots. Soil erosion was also a byproduct of the individualization of *Musha* lands. In order to maximize agricultural area, communal erosion banks and windbreaks were being torn down (Fischbach 2000).

By 1950, the Amman governorate included 11,408 owners that controlled 1,017,236 dunums of land (1000 dunum = 1 km$^2$ or 1000 m$^2$). In Madaba the figures were lower, with 7,551 owners owning an area of 604,913 dunums (Fischbach 2000). Table 3.2 shows the breakdown of sizes for each governorate:

**Table 3.2:** Size of Landholdings in 1950 (Dunums)

| ***Governorate*** | ***< 100*** | ***100-200*** | ***200-300*** | ***300-500*** | ***> 500*** | ***Total*** |
|---|---|---|---|---|---|---|
| Amman | 9,655 | 999 | 306 | 197 | 251 | 11,408 |
| Madaba | 6,083 | 695 | 288 | 246 | 239 | 7,551 |
| | | From Fischbach 2000 pg.151 | | | | |

As demonstrated, in Amman, 84% of landowners were small scale agriculturalists while in Madaba, the number is slightly lower at 80%.

Ottoman laws have been the main impetus for contemporary Jordan land laws. These laws affect the way that land is inherited and subsequently how the land is parceled out. As demonstrated previously, changes in land allocation and land use are one of the driving factors of soil degradation. An understanding of the categories of landholdings in the region is worth noting as certain types of holdings can only be used for specific purposes that may or may not promote environmental degradation. Furthermore, as this study proposes to examine the association of land fragmentation in relation to aquifer level depletion, it is important to understand one of the devices that causes fragmentation in the region (inheritance). Historically, modifications in laws have effected revenue and crop yield as the incentive for farming changes. In the case of a plot that has multiple owners, this may cause one to sell their share to an outside source, which may be used for a different purpose then the majority, causing a further fragmentation of the landscape.

**Water Law and Policy**

Similar to land laws, water law and policy is important to understand for this study due to different laws applying to different water uses. Laws pertaining to agriculture differ from those pertaining to municipal and industrial purposes. The amount of allowable water withdrawal for agriculture is governed by these laws, and these policies help conserve water usage throughout the country.

Water laws regarding use can be found throughout history. In 2400 BCE, the Assyrians approved laws to regulate irrigation (Jastrow, 1921), and subsequent civilizations, such as the

Egyptians also had laws in place to regulate water usage (Bruch et al. 2007). There is cultural and religious significance regarding water in Jordan dating back to the earliest days of both Christianity and Islam. John the Baptist used the Jordan River for the baptism of Jesus Christ approximately 2000 years ago, and this ritual continues today among Christians arriving from across the globe. Among Muslims, water is used for *wadu*, the cleansing ritual that must be done before prayer. In fact, ablution fountains often designate the entrance to mosques across the Muslim World. In Islam, there is the concept of *khalifa,* where humans are seen as caretakers of the earth‟s resources (Amery 2001).

Islam grants some universal human rights which are to be observed and respected at all times. This justifies any action that will lead to the welfare of an individual or a society. There is a hierarchy of relationships that welfare must travel in an Islamic society (Khordish 2004). This usually follows the immediate family (parents, spouse, children), followed by extended family, neighbors, friends, aquaintances, orphans and widows, the needy in the community, fellow Muslims, and finally fellow man (Khordish 2004).

Islamic law classifies water into 3 distinct ranks: common, private, or public domain (Lancaster, 1999). Common waters are associated with seas, lakes, marshes and rivers, as well as water flowing underground. Wells that have been dug up by an unknown person is also considered common. The private classification stems from all waters that are on or under privately owned land. Examples of this are cisterns, underground basins and springs. Continually running water, such as rivers or streams, can be considered either private or public domain but this is dependant on specific situations. For example if the running water is located on private property or the destination of flowing water is on privately owned land then the water is considered private.

Ownership of water in the Jordan is of vital importance due to the scarcity of the resource. There is a perception among some people that Islam has declared that water is free, and should not have a cost associated with it (Haddadin 2006). This perception is primarily due to a quote by the prophet Mohammad that stated “People are partners in three: water, pasture, and fire”. This is true in the fact that there are certain rights to water, such as the right of thirst (Faruqui 2001, Lancaster 1999) which may be exercised without payment. This law allows a person and livestock access to drink from all waters that naturally replenish themselves. Water used for irrigation may or may not be free depending on which category the water is placed into. Common and public water can be used freely, while private water cannot. Also in regards to common and public water, there are a number of different priorities as to who can use the water. Water upstream has a larger priority then downstream waters, users closer to the riparian system have more priority than those farther out, and older cultivated lands have a higher priority then newly established agricultural lands (Lancaster 1999). The issue of irrigation in the private classification can be sold or given at the discretion of the landholder.

Although water from public lands is not allowed to be sold under Islamic law, a fee can be administered if an effort has been made to obtain and transport it (Haddadin 2006). For example, a government has the authority to charge for the transportation of water used for municipal use because this is considered a service, and the service is being sold.

Treatment and reuse of wastewater is also allowed under Islamic law (Haddadin 2006). A *fatwa* was issued dated 25/10/1398H (hijri calendar) stating that treated waste water could be used not only for drinking, but also for wadu. In Jordan, treated wastewater has specifically been used for both irrigation and for power providing purposes. Currently, only Jordan is making serious re-use out of greywater (Brett-Crowther 2008).

In Jordan, water legislation dates back to 1936 during the time of the British Mandate (Haddadin 2000) and became more detailed in the 1950s to assist with irrigation of the Jordan Valley. Early legislation dealt with settlement of land and water rights. In 1954 legislation was introduced to manage irrigation through governmental projects. This legislation fell under the Water Department of the Ministry of Public Works jurisdiction. In 1959 two pieces of legislation were created: The first, produced the East Ghor Canal Authority. A second, separate legislation was enacted that dealt with municipal water supplies and subsequently created the Central Water Authority. In 1965 the two merged to form the Natural Resources Authority (Haddadin 2006, 2000). The Jordan Valley Commission was created in 1973 to care for planning of projects specific to the Jordan Valley. In 1974, the Domestic Water supply Corporation was created that took over the Natural Resources Authority responsibility for supplying water to population centers. By 1977, more legislation was enacted that that created the Jordan Valley Authority, who took over responsibility for the East Ghor Canal project. The Water Authority was created in 1983, with the purpose of "exploration, development, conveyance and distribution of water, with the exception of irrigation projects"(Haddadin 2000). Before this time, municipalities were responsible for the distribution of water to the population. At the onset of the new Authority, approximately 10,000 municipal workers became a part of the central government. In 1988, the Ministry of Water & Irrigation was created and administered the Jordan Valley Authority, and the Water Authority. Haddadin (2000) points out that the frequent changes in these institutional arrangements were disruptive in the implementation of various laws and development projects.

The overriding concern of the various mergers is the effect it has on the subsequent management practices dedicated to water policies. Haddadin (2000) wrote that as professionals from various backgrounds were merged and formed factions. This in turn led to a less productive workspace where people were rewarded on the basis of "*wasta*", in other words, "it"s not what you know, it"s who you know". Promotions, scholarships, and other rewards were being subjectively influenced by this phenomena.

Another aspect of the mergers was the lack of payments rising to support the cost of living. Haddadin (2000) states that government workers had formed the bulk of the middle class, but as cost of living was raised, they became lower middle class. This in turn affected the quality of work, as well as the loyalty of workers who became more susceptible to influence from special interest groups.

Current water policy in Jordan holds that agriculture is lowest in priority behind municipal and industrial water needs in Jordan, and is highest in priority in the allocation of treated wastewater (Haddadin 2006). In 1995, Jordanian farmers were getting water at 1-2 cents/$m^3$ (Brooks 1997), due to heavy subsidiaries from the central government. The results of the subsidization caused 25% of arable land to be irrigated, but which was allocated 63% of total water resources. In 1995, the price of water more than doubled, and an increasing block tariff system was introduced. Bruch et. al(2007) explains that:

> "In an increasing block system, charges are calculated based on volume consumed, thereby allowing wide access (with the basic allotment being the cheapest) but encouraging conservation (by charging increasing more for greater usage). Thus, the more blocks a consumer uses, the higher the price"

After the implementation of the block tariff, irrigation efficiency in the Jordan Valley reached 70% in 2000, up from 57% in 1994 (Haddadin 2006). The imposition of the tariff was staggered as to not interfere with market pricing of goods. The pricing of water went from US\$0.0052/$m^3$ in 1989 to US\$0.031/$m^3$ in 1995 and rose to US\$0.04/$m^3$ in 2000 (Haddadin 2006). The total operation and maintenance cost of irrigation in the Jordan Valley totals

US$0.05/$m^3$, while the revenue averaged US$0.015/$m^3$, which leaves approximately 70% of the cost to be subsidized by the Jordanian Treasury. The block tariff for delivered water is demonstrated in table 3.3.

With the introduction of Jordan into the World Trade Organization, there has been a decrease in the amount of agricultural revenue. This, coupled with decreased trade of agriculture within the region has had an increased debt burden on indigenous agriculturalists. Licensed wells extracting groundwater in the Highlands are not subject to any charges, save when the user extracts more then the allotted amount of 150,000 $m^3$/yr (Haddadin 2006). In cases of over abstraction of liscensed wells of 151,000-200,000 $m^3$/yr, the user is charged US$0.035/$m^3$ and more then 200,000 m/yr, the charge is US$0.085/m3 (Haddadin 2006). Although the user receives water for no cost, they pay for costs of operation and maintenance without government assistance. Water extraction costs associated with unlicensed wells is shown in table 3.4.

**Table 3.3:** Current Irrigation Water Tariff

| ***Water delivered (m3/month)*** | ***Tariff (US$/month)*** |
|---|---|
| 0-2,500 | 0.01 |
| 2,501-3,500 | 0.02 |
| 3,501-4,500 | 0.03 |
| Greater then 4,500 | 0.05 |

From Haddadin et al, 2006 pp. 124

**Table 3.4:** Non-licensed Well Costs

| ***Water pumped (m3/yr)*** | ***Charges (per m3)*** |
|---|---|
| 0-100,000 | US$0.035 |
| 101,000-150,000 | US$0.042 |
| 151,000-200,000 | US$0.050 |
| More then 200,000 | US$0.098 |

Taken from Haddadin et. al pp. 126

Water cost between 1993-2002 for municipal and industrial uses are estimated at US$1.12/m$^3$ and only generate revenue of US$0.637/m$^3$, and requires a subsidy of US$0.478/m$^3$(Haddadin 2006). As poverty in Jordan rose from 3% in 1987 to 12% in 1997, consumers who use less then 20 m$^3$ of municipal water per quarter per connection were considered when the municipal water tariff came into effect. In 1997, the tariff was increased from US$0.28 to US$0.49 for the lowest usage block (Haddadin 2006). Table 3.5 illustrates the price per block.

**Table 3.5:** Municpal Water Price (US$/m3).

| ***Water Block (m3)*** | ***1980-1985*** | ***1986-1988*** | ***1988-1990*** | ***1990-1996*** | ***1997-2001*** | ***2001-2003*** |
|---|---|---|---|---|---|---|
| 0-20 | 0.3 | 0.28 | 0.28 | 0.28 | 0.41 | 0.49 |
| 21-40 | 0.32 | 0.27 | 0.24 | 0.24 | 0.24 | 0.31 |
| 41-70 | 0.44 | 0.4 | 0.38 | 0.38 | 0.41 | 0.72 |
| 71-100 | 0.58 | 0.55 | 0.54 | 0.58 | 0.62 | 1.12 |
| 101-150 | 0.72 | 0.71 | 0.69 | 0.78 | 0.82 | 1.38 |
| 151-250 | 0.81 | 0.83 | 0.83 | 0.95 | 1.03 | 1.77 |

Taken From Haddadin et. al (2006) pp. 129.

Selling water services promotes three specific functions: recognition of environmental importance to the efficient use of water; promotes cost recovery of the operation and management of the water utility; raises consumer‟s awareness of the cost of water delivery and provides a reason to conserve water (Bruch et al. 2007).

The overwhelming constraint that faces every country in an arid region like the Levant is that of water is scarcity. Although water usage is lowest per capita, water demand far outpaces other renewable resources (Dal Santo and al Naser 2001). Water allocation laws vary from country to country. Article 6 of Jordan‟s Water Authority Law No. 18/1988 allows the Water Authority to "survey the different water uses, conserve them, and determine ways, means and priorities for their implementation and use" (Bruch et al. 2007). The same law also refers to a permitting system for drilling wells, however, By-Law No. 85/2002 was created to control over drafting of groundwater, prevent illegal well drilling, provide penalties for illegal use and to promote the use of brackish ground water for irrigation (Taha, 2006). Article 3 of the aforementioned by-law requires groundwater users to obtain licenses for pumping. To receive a license the applicant must stipulate to a number of criteria: type of usage, extraction quantity within the time period, and an installation of a water meter. These licenses are renewable after 1 years‟ time (Bruch et al. 2007). The methods in this study may be able to help monitor both water usage and land use for licensing purposes.

Wastewater reuse is also regulated in Jordan with standards that have been issued by Jordan‟s Institution for Standards and Metrology (Bruch et al. 2007). The Reclaimed Domestic Wastewater Standard No. 893/2002 is used by the Water Authority of Jordan for wastewater treatment plants. The purpose of this standard is to set quality criteria for the release of wastewater back for reuse. This is done for a number of categories including: discharge of wastewater, artificial recharge of aquifers, irrigation of vegetables to be cooked, irrigation of fruit trees, and irrigation of crops. This standard prohibits the use of treated wastewater on vegetables that are not to be cooked. The other 2 standards are the Industrial Wastewater Standard No. 101/1992 and the Reuse of Treated sludge in Agriculture Standard No. 1145/1996 (Bruch et al. 2007).

Drinking water standards in Jordan are largely modeled after standards set by the World Health Organization (Bruch et al. 2007). Jordan‟s Law on the Environment No. 12/1995 prohibits the discharge of environmentally harmful substances into public water (Bruch et al. 2007). Water quality standards generally depend on a body of waters intended use. For example, water used in artificial aquifer recharge cannot exceed a nitrate concentration of over 30 mg/l. Artificial aquifer recharge is the practice of purposely reintroducing water from the surface to an aquifer. This may be done through methods such as a dam or a infiltration well using gravity, or pumps from areas such as wastewater treatment centers (Bouwer 1999). As far as non point source pollution is concerned, Jordan has yet to create laws that specifically addresses this aspect of water quality.

Jordan‟s framework for governing water has moved from a decentralized to a centralized approach, in which the central government is responsible for all water related issues (Bruch et al. 2007). Jordan‟s By-Law No. 54/1992 gives the Ministry of Water & Irrigation full responsibility for water and public sewage as well as any projects pertaining to it. There are however decentralized aspects to this centralized approach. Jordan‟s Water Authority Law No. 18 allows a Water Council to be established that is staffed from representatives of the public sector, private sector, and local citizens (Bruch et al. 2007). Although centralized, management is divided between a number of ministries. The responsibility for ensuring the safety of drinking water is given to the Ministry of Health, but the responsibility for quality monitoring is divided between the Ministry of Water & Irrigation, the Ministry of Health, and the General Corporation for Environmental Protection (UNESCWA 2003).

In Jordan, water is held as state property decreed by Jordan‟s Water Authority Law No. 18 which states:

> "all water resources available within the boundaries of the Kingdom, whether they are surface or groundwaters, regional waters, rivers or internal seas are considered state owned property"(Bruch et al. 2007).

The aforementioned law also allows the contracting of water management responsibilities to both the public and private sectors. This has led to the formation of public-private partnerships (PPP) that are more efficient and effective then just one sector (Attia 2005).

In 1997, Jordan endorsed reforms which led it to become one of the first countries in the region to make use of PPP arrangements. The types of contracts awarded to the private sector vary from management contracts to Build, Operate, Transfer (BOT) contracts. According to Bruch et al. (2007) a recent BOT contract was awarded to a private company for a wastewater treatment plant for Amman. Another contract was awarded to a separate company to attempt to make water delivery more reliable. This contract resulted in significant improvements to water supply and delivery, staff training, reduction in water loss, higher revenue, lower operating costs and improved network repairs (Attia 2005).

As can be seen, Islamic water law plays a vital role in in perceptions of water usage and availability. When people believe the water to be free, they are more likely to use it. As Jordan specific water laws were implemented in the Jordan Valley, efficiency rose to 70%. As governance of water moved from decentralized to centralized control, and water cost increased, water usage became more effective.

**Social Perception of Risk**

Assessing risk through the perceptions of those that may be affected by an impending disaster can help form policy to circumvent it. Nowhere is the study of risk in regards to hydrological issues more critical than in the Middle East, where populations are increasing, agricultural practices are expanding and water supplies are running out. This concept is best proposed by Slovic (1987) who maintains that "the ability to sense and avoid harmful environmental conditions is necessary for the survival of all living organisms.

Perception is defined as the act of apprehending by means of the senses or mind. The concept of perception has been discussed since the time of Plato (Paradise 2005) and refined by a number of scholars throughout time. Freud (1929) describes the interactions of reality and the psyche and explains how external factors such as sexual motivation and religion can affect the psyche, thus affecting perception. Jung (1944) differentiates between perception and judgment, explaining that perception is the acquisition of data from the world, while judgment is how we arrive at conclusions derived from perception. It is in this division that an individual may use religion to judge what was perceived in a particular way.

The core variables in risk perception research are the perceived magnitude of risk and risk acceptance. Once information is received, intuitive heuristics takes place (Renn et al. 2000). These are common sense mechanisms that process the information and help a person draw conclusions. People can be risk averse if the perceived losses are high, and risk prone if gains are potentially high. Most people balance risks by pursuing an optimal risk strategy that does not maximize benefits but also minimizes disaster (Renn et al. 2000).

Slovic et al. (1982) further state that the psychometric paradigm that leads to heuristic decisions may also lead to a "large and persistent bias with serious implications for risk assessment." The use of psychophysical scaling methods and multivariate analysis to produce quantitative representations of risk and perceptions is known as the psychometric paradigm (Slovic et al. 1982). Researchers employing the paradigm typically ask participants to calculate the current and desired risk or safety of hazardous activities and compare them to the hazard"s status on characteristics that have been hypothesized, such as dread or knowledge. Slovic et al. (1982) came up with a number of relevant results:

1) Perceived risk is quantifiable and predictable.
2) Risk means different things to different people.

3) Even when groups disagree about the overall riskiness of specific hazards, they show remarkable agreement when rating those hazards on characteristics of risk such as knowledge, controllability, dread, etc.

4) Many of the risk characteristics are highly correlated with each other, across a wide domain of hazards.

5) Many of the various characteristics of risk correlate highly with the laypersons‟ perception of risk.

6) People‟s tolerance for risk appears to be related to their perception of benefit.

Fischhoff et al. (1981) attempts to examine approaches to acceptable risk following a number of steps.

1) Define acceptable risk decisions and identifying some frequently proposed but inappropriate solutions.

2) Characterizing the features of acceptable risk problems that make resolving them difficult.

3) Classifying decision making approaches according to how they attempt to address the features of acceptable risk problems. There are 3 methods of doing this: professional judgment, which allows experts to devise solutions; bootstrapping searches for historical precedents to guide future decisions, and formal analysis, which are theory based procedures for modeling problems and calculating the best direction

4) Specifying the objectives that an approach should satisfy in order to guide social policy.

5) Assess how well the approaches meet these objectives.

Wildavsky and Dake (1990) discuss four theories of risk perception: the knowledge theory, personality theory, economic theory and the cultural theory: *the knowledge theory* holds that something is dangerous because it is known to be dangerous. One measure of knowledge is an individual‟s self-report on a particular subject. Questions such as "How much do you know..." or "How aware are you of..." can give a quantifiable answer on what the perception of the participant for a particular subject. As a general trend, Wildavsky and Dake (1990) have found that participants that have rated their self-knowledge higher in regards to certain technologies also perceive greater benefits from those technologies. However, other than benefits of technology, the authors contend that self rated knowledge has a minimal relationship with risk perception.

The *personality theory* addresses individuals whose perceptions are different from one another, i.e. one person is prone to risks such as skydiving, while another avoids risks as much as possible (Wildavsky and Dake 1990). There are two versions of the economic theory (Wildavsky and Dake 1990); one where the rich are more willing to take risks stemming from technology, because their wealth allows them to be shielded from adverse effects. The other economic theory is opposite and contends that because the rich have what they need, they are more prone to aspire to post materialistic values such as health and closer social relations. Finally, cultural theories uphold the notion that individuals choose what to fear as an instrument to support a certain way of life (Wildavsky and Dake 1990).

In his study on seismic risk in Morocco, Paradise (2005) contends that familiarity with frequent events dramatically decreases the risk associated with those types of events, while cultural aspects have been found to effect perception of risks. An example of this comes from Christensen and Ruch (2007) who wrote of the response to incoming hurricanes on the Coast of the Gulf of Mexico. Due to the high frequencies, many people do not evacuate, and instead throw “hurricane parties” to pass the time during a hurricane.

Culture and religion also play an important role in the perception of risk, and nowhere is this more prevalent then in Islamic societies. Fatalistic approaches to natural disasters are quite common, and in many cases are described as the “will of Allah”, especially in regards of poorer people (Ittelson 1960). In a study by Paradise (2005), the most common shared perception pertaining to a natural disaster was that of “Allahu a‟lam” (only God knows). Perceptions such as this one can make deriving a sensible policy more difficult in that the participants‟ minds are already made up on what will happen to them in the case of another disaster. Hartmann and Boyce (1987) found that wealthier adherents of the Muslim faith were more likely to have an attitude of “Allah helps those who help themselves”.

Heider (1958) contends that the origin of the disaster does tend the matter in regards to risk perception. Disasters such as hurricanes and earthquakes are attributed as an act of God, however in many cases water shortages are an act of man. This can have a profound effect on perception in that some disasters cannot be averted no matter what is done, while the cause of other disasters may be blamed on an individual, or on society‟s actions. Paradise (2005) wrote of the role of the Golcuk Mosque in Turkey that was left standing after an earthquake had devastated the surrounding area. This supported the notion that the adherents of this mosque were safe, while the rest of Turkey was being punished for de-emphasizing religion and supporting the European Union.

### Summary

The examination of historical climate change is valuable in that the phenomena that have shaped the landscape still occur today. Human induced climate change has caused more extreme events to occur, and as Lucke (2007) defends, these events are major cause for landscape change in Jordan. With Jordan presently experiencing drought like conditions (Namrouqa 2009), a major precipitation event may cause a significant change to the landscape in the upcoming years.

It is also important to examine human induced environmental degradation as this takes place at a local scale. The multiple studies included in this chapter provide definitive proof that certain types of landuse can cause degradation. Agricultural practices have led to desertification and salinization of historic areas in Jordan. Similarly, deforestation for both agricultural and industrial purposes has also made an impact on the Madaba region.

Land ownership classifications from the Ottoman period are still in use today and are used for different things. *Mushu* (communal ownership of land) societies still exist in some areas of Jordan, and have the potential to cause a fragmentation of agricultural plot sizes if agreements cannot be reached between villagers that own the rights. *Milk* land is privately owned and may be used for multiple purposes, while *Miri* lands are publically owned and typically leased to agriculturalists. A *Waqf* is an endowment of land for a charitable or religious public causes. *Matruka* lands are non-arable lands that have been set aside for public good and are used for markets, pastures, or forested areas used for firewood. Finally *muwat* lands are isolated lands that are not used for anything.

As the Ottoman empire declined, the British imposed colonial type laws and taxes in an effort to create higher efficiency. *Mushu* landholdings were divided into individual plots. A result was that plots would become more fragmented through time, which lead to higher erosion rates.

Islamic laws have been interpreted by some to mean that water is free for all people. This however is not the case as the cost of processing and transporting water must be addressed. Islamic law also classifies water into three categories that have an important impact on water uses. Common and public water can be used for by the public at large, while private water is used by a landowner at their own discretion. Groundwater is considered common and it‟s use is regulated by the authorities in Jordan.

Jordan‟s Law No. 18 specifically gives ownership to all water within the country to the central authority. As Jordan‟s water distribution moved from municipal based to a centralized distribution, many government agencies were merged together. These agencies form the Ministry of Water and Irrigation, Natural Resources Authority and the Ministry of Agriculture among others. These ministries have made it a policy that agricultural is now the lowest priority for fresh water, but highest priority for treated waste water.

Although water used for agricultural purposes is still heavily subsidized, water prices have been have been steadily increasing as to cover the increasing costs as water becomes more scarce. This has led to an increased use of technologies such as drip agriculture.

These laws set the stage for understanding agriculturalist mentality when dealing with water and landuse. It is important to understand how people perceive risk in regards to the hazard of scarcity of water in order to form policy that may circumvent the impending disaster.

# Chapter 4: Methodology

The purpose of this research methodology was to develop (a), Likert scale surveys (b)groundwater maps from data obtained from the Ministry of Water and Irrigation, and (c) land use classifications maps from remotely sensed data. Likert scale surveys were created to better understand the regional social perceptions of water use and risk. Both groundwater maps and the land use classifications were created to determine if current irrigation practices in agriculture have an adverse effect on ground water levels.

## Likert Scale Survey Methodology

A written survey was created to assess awareness of different aspects of water concerns along with general demographic statistics. These questions utilized a Likert scale method (Anastasi 1982) that measured self-identified awareness on a scale of 1-5, with 1 being least aware, and 5 being very aware. The survey was translated from English to Arabic to facilitate easier communication with the target respondents.

The focus was on the urban centers of Amman, Madaba and the region of Um al-Basateen, (figure 4.1) an area between Amman and Madaba. Areas of high pedestrian traffic were targeted including, but not limited to cafés, mosques, and restaurants. The targeted participants included land owners as well as tenants. In many cases, farmers working on their fields were also asked questions while they were harvesting crops. It must be noted that one of the locations where the surveys were administered was at the University of Jordan in Amman and that may explain the relatively high percentage of post graduate degrees included in the study.

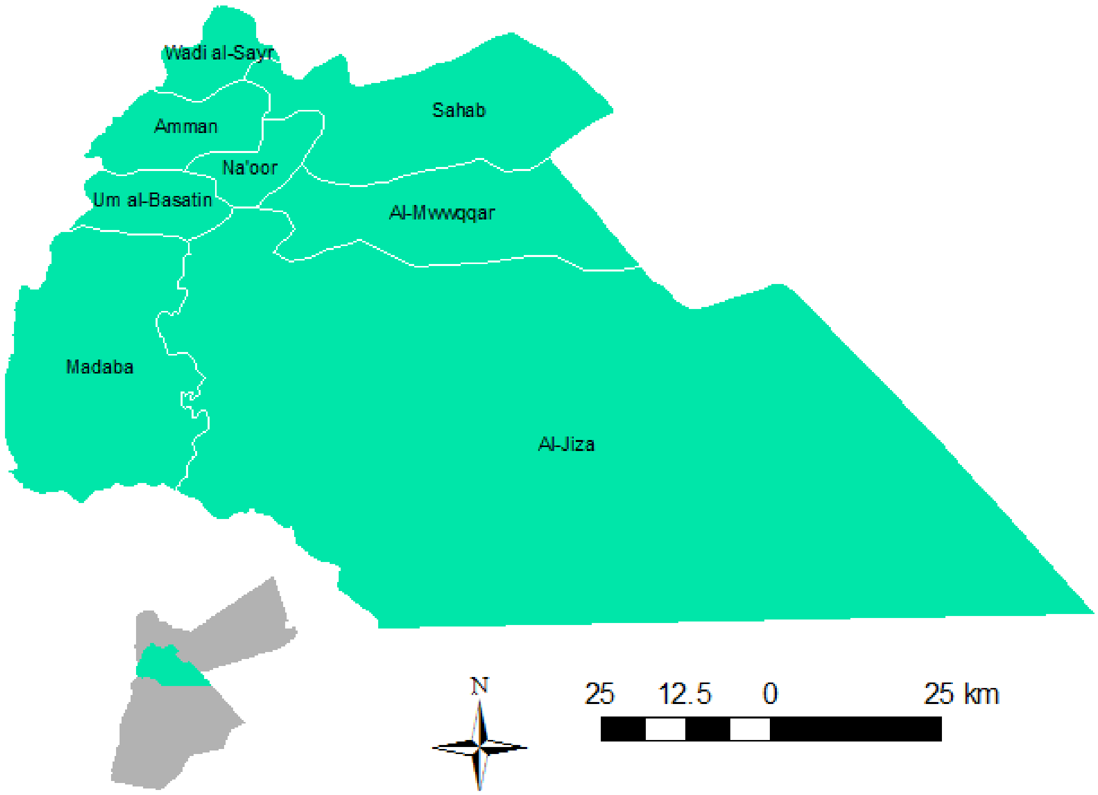



**Figure 4.1:** Subgovernorates of the Amman region. Madaba was included as a part of the study area, but is not one of Amman's subgovernorates.

A helper from the ministry of education in Madaba assisted in order to facilitate the completion of the surveys in the cases where participants were illiterate or in need of assistance.

The survey consisted of six check boxes pertaining to general demographic questions such as gender, income, marital status, age, education and employment. There were also questions pertaining to specific land use and water usage. Finally, seven questions were administered that required a Likert (scale) response:

1. Overall, how knowledgeable are you about overpumping aquifers for agriculture?
2. How knowledgeable are you about water mining?
3. How knowledgeable are you about water quality?

4. How knowledgeable are you about water runoff?
5. How knowledgeable are you about desertification?
6. Are knowledgeable are you about water conservation methods or water-saving technologies?
7. Are you aware of any changes in landuse for your land?

A total of 224 surveys were completed, and included in the study.

**Water Depth and Land Use Methods**

The time periods for the study survey were based on two primary factors: (a) the availability of ground water depths and (b), the availability of cost effective satellite imagery (Kettle et. al 2007). Groundwater depths were ascertained from well depths provided by the Ministry of Water and Irrigation's Water Information System. Monthly depth to water figures were given for a total of 52 locations in and buffering the study area. Temporally, the range extended from 1986 to 2007. These figures were available through the Ministry of Water & Irrigation in excel spreadsheet format that consisted of over 6400 records.

The data were then averaged for annual values for the years of 1986, 1991, 1998, 2002, and 2007. It must be noted that the number of points were not equal between all years, and that some data were omitted due to lack of data in that yearly record (table 4.1, figure 4.2, appendix D-2). Hadaddin (2006) writes that data collection did not begin to be regulated in earnest until 2000. The data were then joined to a shapefile of well locations provided by the Ministry of Water and Irrigation to produce well depth point data.

**Table 4.1:** Distribution of Points per Monitoring Station

| ***STATION_NAME*** | ***1986*** | ***1991*** | ***1998*** | ***2002*** | ***2007*** |
|---|---|---|---|---|---|
| ABU E'LAYYAN OBS | | | | | |
| AIN EL RUSEIFA 8 /OBSERVATION | | | | | |
| AIN GHAZAL DEEP NO 4 | | | | | |
| AIN GHAZAL STATION 2 (NEW) | | | | | |
| ARAINBEH NO 4(OBS.) | | | | | |
| AWAJAN OBSERVATION | | | | | |
| AWSA 5 NOUREDDEEN | | | | | |
| AWSA SEIL EL RUSAIFEH NO 3 | | | | | |
| BREAK OBS. NO 1 | | | | | |
| DABB'A NO (S 70) | | | | | |
| DHUHEIBA AL SHARQIYA NO 3 | | | | | |
| HEEDAN NO 2(OBSERVATION) | | | | | |
| KHAN EL ZABEEB MONITORING | | | | | |
| MADABA WASTEWATER T.PLANT 1 | | | | | |
| MADABA WASTEWATER T.PLANT 2 | | | | | |
| MADOUNEH NO 2 | | | | | |
| MADOUNEH NO3 | | | | | |
| MADOUNEH NO4 | | | | | |
| MAQARR INVESTIGATION 14B | | | | | |
| MERCURY 5 | | | | | |
| MUWAQQAR(KM 6) | | | | | |
| QASTAL NO 7 (OBS.) | | | | | |
| RACE CLUB NO 13 | | | | | |
| RACE CLUB NO 18 | | | | | |
| RUSEIFA LANDFILL MONITORING 3 | | | | | |
| RUSEIFA MONITORING 1 | | | | | |
| RUSEIFA MUNICIPALITY 1 | | | | | |
| SUPPLY OBSERVATION | | | | | |
| TAFEH SOUTH MONITORING 2 | | | | | |
| UM EL RASAS OBS. NO 1 | | | | | |
| WADI EL QATTAR 1 | | | | | |
| WADI EL QATTAR 7 | | | | | |
| WADI HAMMAM NO 4 (PP 86) | | | | | |
| WADI I'SHASH MONITORING 1 | | | | | |
| WALA NO 11 OBSERVATION | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| WALA NO 14 | | | | | |
| YAJUZ 1 MONITORING | | | | | |
| YAJUZ NO 1 | | | | | |
| YAJUZ NO 6 | | | | | |
| ZERQA OBSERVATION 1 | | | | | |
| ***Total Points*** | 11 | 12 | 14 | 37 | 36 |

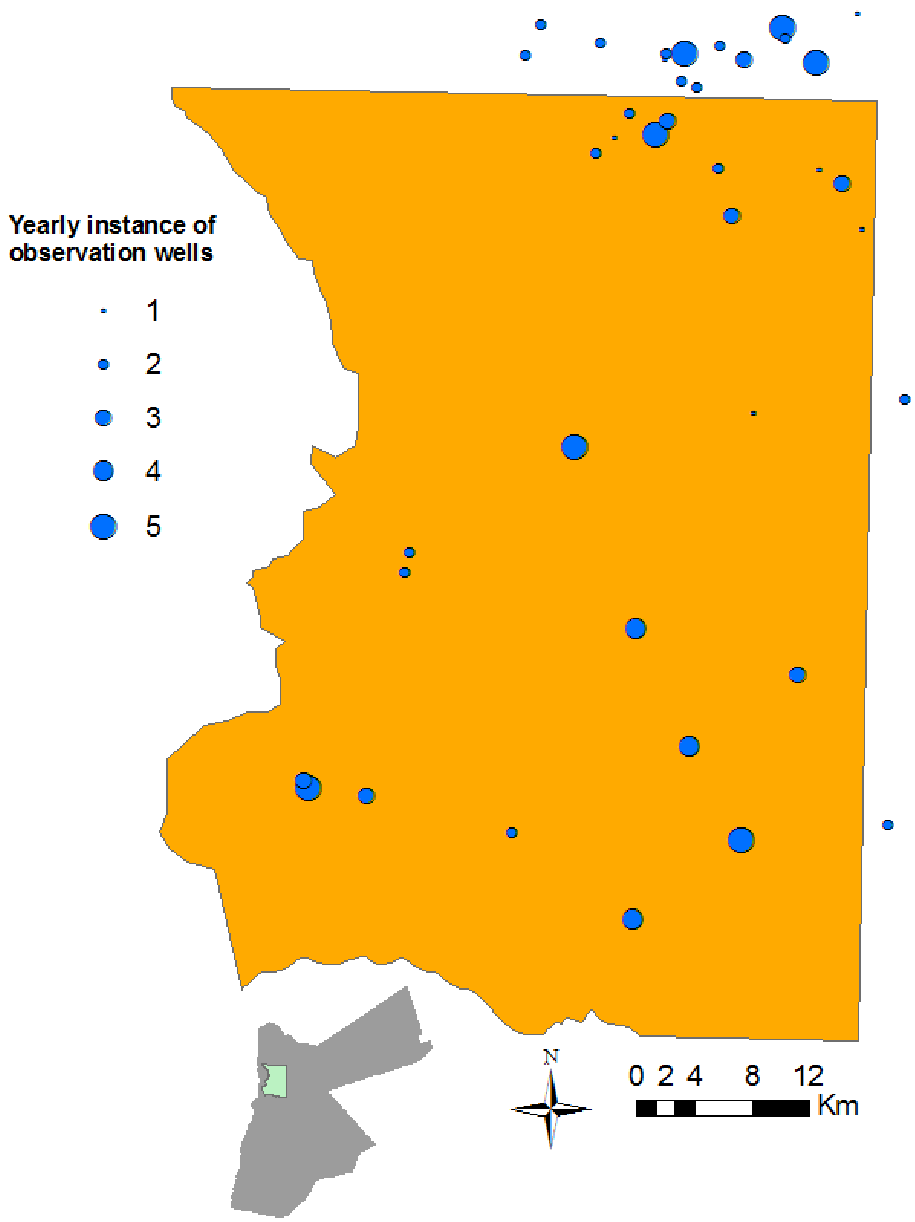



**Figure 4.2:** Spatial distribution of observation wells used for interpolation in the study site area.

To create a depth to water level surface map, a number of interpolation operations were attempted. This was done to discern the lowest amount of errors associated with the data, as is noted in table 4.2. For this study, Universal Kriging was selected for 2 reasons. First, as can be seen from the table 4.2, the relative error between the tested methods is low, particularly in cases with a higher sample sizes. Although all the techniques in table 4.2 are exact interpolators, all Kriging methods have the opportunity to demonstrate discontinuity at the sample point if there is a nugget effect. Exact interpolators respect the original data as it allows for the interpolated surface to pass through the collected data points. All tested methods allow for an estimation of the reliability of the data at unmeasured sites by cross validating known measurements with the predicted estimates. Second, Universal Kriging takes into account trends in the data, while Ordinary Kriging is based on a constant mean. The data collected from the Ministry of Water and Irrigation was found to show a second polynomial trend. Universal Kriging also minimizes the mean squared prediction error and uses weighted local averages to determine unbiased estimates at unverified locations ( Bolstad 2002, Cressie 1989, Burgess and Webster 1980). Universal Kriging has been used in a number of depth to water studies (Sun et. al 2009, Kettle et. al 2007, Dunlap and Spinazola 1981).

**Table 4.2:** Error of interpolation methods.

| ***year*** | ***Method*** | ***Mean*** | ***RMSE*** | ***Average Standard Error*** | ***Mean Standardized*** | ***RMS Standardized*** |
|---|---|---|---|---|---|---|
| 1986 | IDW | -8.339 | 39.57 | | | |
| 1986 | Radial Basis Function | -4.86 | 31.9 | | | |
| 1986 | Ordinary Kriging | -5.394 | 38.5 | 51.4 | -0.03258 | 0.755 |
| 1986 | Simple Kriging | -11.36 | 41.07 | 55.3 | -0.1294 | 0.7275 |
| 1986 | Universal Kriging | -5.477 | 38.93 | 51.22 | -0.03608 | 0.7581 |
| | | | | | | |
| 1991 | IDW | -7.947 | 46.28 | | | |
| 1991 | Radial Basis Function | -8.989 | 43.99 | | | |
| 1991 | Ordinary Kriging | -5.337 | 38.53 | 52.11 | -0.03235 | 0.7389 |
| 1991 | Simple Kriging | -11.15 | 40.58 | 57.24 | -0.1214 | 0.6919 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1991 | Universal Kriging | -5.401 | 38.97 | 51.95 | -0.03543 | 0.741 |
| | | | | | | |
| 1998 | IDW | -8.202 | 49.21 | | | |
| 1998 | Radial Basis Function | -3.813 | 46.63 | | | |
| 1998 | Ordinary Kriging | -9.964 | 46.92 | 49.44 | -0.05599 | 0.9587 |
| 1998 | Simple Kriging | -10.16 | 55.13 | 57.55 | -0.1486 | 0.9302 |
| 1998 | Universal Kriging | -9.736 | 45.41 | 51.7 | -0.05256 | 0.8976 |
| | | | | | | |
| 2002 | IDW | -6.913 | 49.96 | | | |
| 2002 | Radial Basis Function | -4.232 | 48.01 | | | |
| 2002 | Ordinary Kriging | -1.948 | 48.93 | 59.39 | -0.008509 | 0.8685 |
| 2002 | Simple Kriging | -9.829 | 57.24 | 67.64 | -0.1258 | 0.8455 |
| 2002 | Universal Kriging | -1.71 | 49.35 | 60.86 | -0.006647 | 0.8488 |
| | | | | | | |
| 2007 | IDW | -8.804 | 56.25 | | | |
| 2007 | Radial Basis Function | -4.514 | 53.11 | | | |
| 2007 | Ordinary Kriging | -2.796 | 51.31 | 57.1 | -0.01627 | 0.9542 |
| 2007 | Simple Kriging | -11.23 | 62.77 | 73.13 | -0.1348 | 0.8467 |
| 2007 | Universal Kriging | -2.423 | 51.81 | 59.23 | -0.0127 | 0.9151 |

The output of Kriging is directly related to the semivariogram of the data. First, the lag size was set to 10 for each process. The lag is a discrete classification for continuous values. The lag was calculated based on the results of the average nearest neighbor tool in ArcMap (table 4.3). The nugget accounts for variance at zero distance. In essence, the nugget is uncertainty in the data that may be attributed to error in the measurements or "noise" within the data. Theoretically, this value should be similar to standard deviation values obtained from averaging the yearly data. The range is the distance at which a semivariogram levels off and beyond which semivariance is constant (O'Sullivan and Unwin 2003). Points within the range are considered autocorrelated. The sill is the constant semivariance value beyond the range (figure 4.4). A smoothing factor of .4 was applied to the data to produce an output that more likely resembles a continuous flow of water.

| **Table 4.3:** Observed distance between points | |
|---|---|
| 1986 | 7342.112533 |
| 1991 | 6895.214426 |
| 1998 | 5947.254689 |
| 2002 | 3920.279453 |
| 2007 | 3701.394738 |

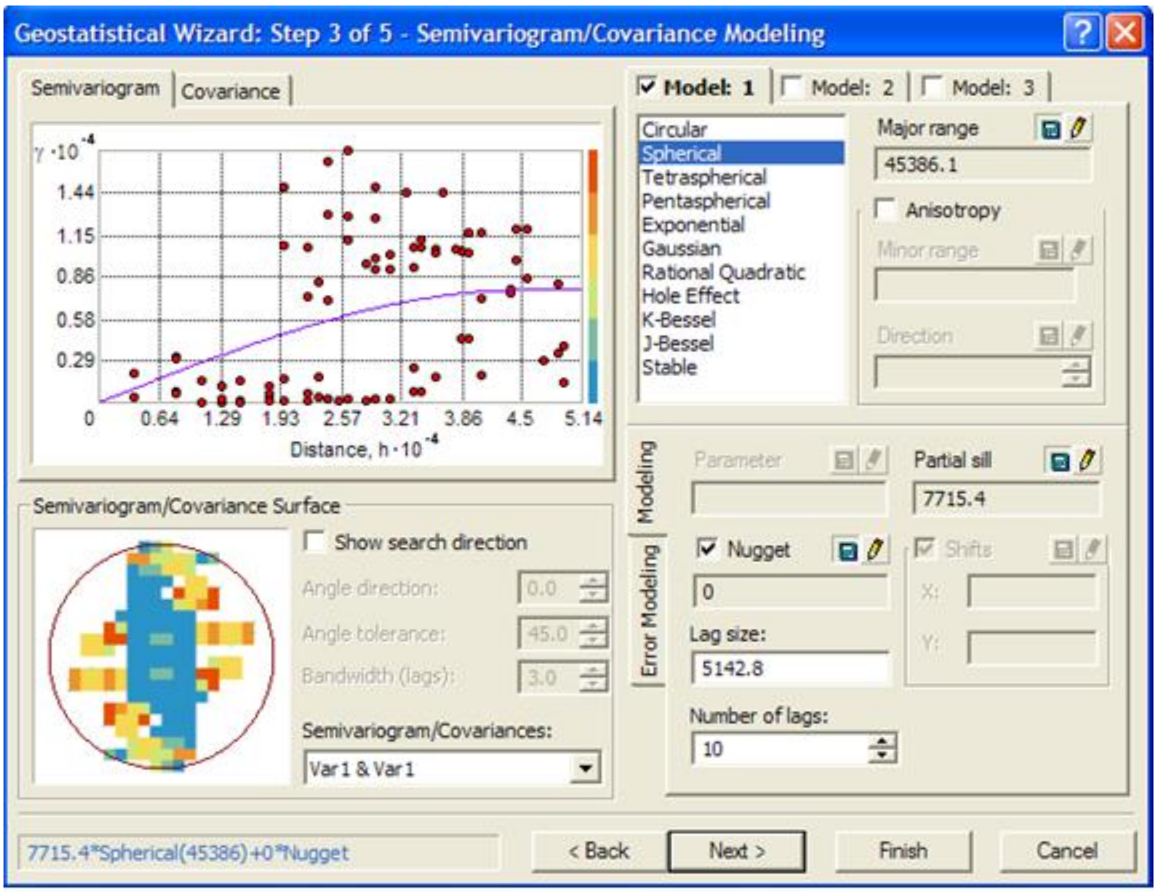



**Figure 4.4:** Semivariogram demonstrating the variables involved in building a model for points associated with the study. (This graphic is the user interface taken from ESRI's ArcMap program.

As the mean error approaches 0, the model becomes more accurate. Root mean square error (RMSE) is based on the square of the errors. This is done so that positive and negative errors do not cancel each other out (Sun et. al 2009, O'Sullivan and Unwin 2003). After a surface is interpolated, the cross validation algorithm removes a control point and estimates the value of that point based on other control points. The smaller the RMSE error is, the more accurate the model will be. The average standard error is a function of Kriging and should be of a similar value to the RMSE. Likewise, the mean standardized value should be close to 0. The RMSE standardized error should be close to 1. It is calculated as the average standard error divided by the RMSE. If the value is greater than 1, then the model underestimates the variability of the data. If it is less than 1, there is an overestimation taking place. The reason for assessing the error in this way is to attempt to create ground water depth maps that are accurate.

The results of this process were then clipped to fit the study area and exported as an .img file. The file used to clip was created from a Jordan base map provided by the Ministry of Water and Irrigation. Using an overlay procedure (Kettle et. al 2007), each time period of the study was subtracted from the period before. For example the output for 1991 was subtracted from 1986 to produce a difference in water levels. The results of the overlay procedures are shown in figure 5.3-5.6. The data were then reclassified into 10 classes using the Jenks classification method and converted into a vector polygon format for further use in the study. The values for the Jenks reclassification are in Appendix B.

The methods for creating ground water depth maps can be summarized by the following:

1) Gather relevant data from the Ministry of Water and Irrigation.
2) Create annual averages from data for the relevant years in the study.
3) Create raster maps using the universal Kriging technique.
4) Convert from raster to vector maps for further analysis.

Due to time frame of the study period, as well as cost associated with acquiring data, Landsat images were collected from www.glovis.gov. Both Landsat 5 TM and Landsat 7 TM images were obtained and used for this study. The TM is a cross track scanner with an oscillating scan mirror with a scene size of approximately 173X 180 km. This instrument is composed of seven bands operating at different wavelengths demonstrated in table 4.4. The TM instrument allows for a more thorough exploration of the agriculture in the area because specific bands (namely band 4) are very well suited for vegetative surveys. Landsat TM data is abundant and relatively inexpensive to obtain. The Landsat data did not need much processing or geo referencing as they were already corrected to Level 1T; procedures for correction of Landsat images are at http://edcsns17.cr.usgs.gov/helpdocs/landsat/product_descriptions.html#terrain_l5_l1t and state:

> "The Level 1T (L1T) data product provides systematic radiometric and geometric accuracy by incorporating ground control points*, while also employing a Digital Elevation Model (DEM) for topographic accuracy. Geodetic accuracy of the product depends on the accuracy of the ground control points and the resolution of the DEM* used. For locations outside the United States, the accuracy of a terrain-corrected product will depend on the availability of local ground control points (GCPs), as well as the quality of the best available DEM. Scenes that have a quality score of 9 and less than 40 percent cloud cover will be automatically processed, and any archived scene, regardless of cloud cover, can be requested for processing through GloVis or Earth Explorer. *Ground control points used for Level 1Terrain correction come from the GLS2005 data set. DEM data used for terrain correction include SRTM, NED, CDAD, DTED, and GTOPO 30. **While most data available at no charge will be processed as Level 1T (precision and terrain corrected), certain scenes do not have ground control or elevation data necessary for precision or terrain correction, respectively. In these cases, the best level of correction will be applied (Level 1G-systematic)"

The scenes in table 4.5 were found to be suitable for the study.

| **Table 4.4:** Distribution of wavelengths for Landsat TM | | |
|---|---|---|
| | ***Wavelength*** | ***Spatial Resolution*** |
| Band 1 | 0.45 - 0.52 (Blue) | 30 |
| Band 2 | 0.52 - 0.60 (Green) | 30 |
| Band 3 | 0.63 - 0.69 (Red) | 30 |
| Band 4 | 0.76 - 0.90 (Near Infrared) | 30 |
| Band 5 | 1.55 - 1.75 (Middle Infrared) | 30 |
| Band 6 | 10.40 - 12.50 (Thermal Infrared) | 120 (L5), 60 (L7) |
| Band 7 | 2.08 - 2.35 (Middle Infrared) | 30 |

| **Table 4.5:** Scenes used for study | | | |
|---|---|---|---|
| ***Scanner*** | ***Path/Row*** | ***Date*** | ***Quality*** |
| Landsat 5 TM | Path 134 Row 38 | 5-Apr-86 | 7 |
| Landsat 5 TM | Path 134 Row 38 | 11-Aug-86 | 9 |
| Landsat 5 TM | Path 134 Row 38 | 10-Mar-91 | 9 |
| Landsat 5 TM | Path 134 Row 38 | 1-Aug-91 | 9 |
| Landsat 5 TM | Path 134 Row 38 | 21-Mar-98 | 9 |
| Landsat 5 TM | Path 134 Row 38 | 28-Aug-98 | 9 |
| Landsat 7 SLC on | Path 134 Row 38 | 24-Mar-02 | 9 |
| Landsat 7 SLC on | Path 134 Row 38 | 14-Jul-02 | 9 |
| Landsat 7 SLC off | Path 134 Row 38 | 6-May-06 | 9 |
| Landsat 7 SLC off | Path 134 Row 38 | 22-May-06 | 9 |
| Landsat 7 SLC off | Path 134 Row 38 | 10-Aug-06 | 9 |
| Landsat 7 SLC off | Path 134 Row 38 | 26-Aug-06 | 9 |

A two-step approach was used to classify landuse data. The first step involved using the normalized difference vegetation index (NDVI) to differentiate between irrigated vs. non irrigated crop land. As Jensen (2000) states: "The time series analysis of seasonal NDVI data have provided a method of estimating net primary production over varying biome types, of monitoring phonological patterns of the Earth's vegetated surface and of assessing the length of the growing season and dry-down periods". The NDVI is ascertained as (NIR-red)/(NIR+red) where NIR is the near infrared band and red is the red band. The NDVI of the summer season was then subtracted from the NDVI of the spring season to produce differences in seasonal vegetation.  The NDVI of the 2006 data was ground truthed with measurements taken during the 2007 summer season.

The second step, as per Kettle et. al (2007), spectral bands of both the spring and summer seasons were stacked into one data set to be processed and classified.  A supervised classification was employed to create a number of classes in the study area using the maximum likelihood decision rule.  The classes are as follows: Urban, Desert, Agriculture, and Natural Vegetation. There were no significant water bodies within the study area to include a water class.  A Magellen hand held GPS was used to collect 67 ground control points that included both irrigated and non-irrigated agricultural plots.  The results (table 4.6) show a 91.67% agreement of the irrigated ground truthing points and irrigated classifications from the 2006 imagery.

It must be noted that the striations in the 2006 image is due to an instrument malfunction. In 2003, the scan line corrector on the Landsat 7 instrument failed.  This caused data acquisition patterns to become zig-zagged, which caused approximately 22% loss of data, mainly along the edges of the acquired scene (USGS 2010).  To mitigate this loss of data, a second Landsat image from the same time period was combined with the first to fill in a fraction of the missing data values. Overall, the striations in areas of heavy agricultural activity were filled in, while striations in the peripheral desert areas remained.  Although these features remained in the study, they were given lower priority due to lack of agriculture in those areas.

**Table 4.6:** Ground-truthing Data

| | ***Irrigated*** | ***Non-irrigated*** |
|---|---|---|
| Irrigated | 11 | 4 |
| Non-Irrigated | 1 | 38 |
| Non-Agriculture | 0 | 13 |
| Total | 12 | 55 |
| Percent agreement | 91.67 | 69.1 |

Another facet of the study was to measure the continuity of the irrigated agriculture class and to discern any effects this may have on water depths. To do this, the landuse data was converted into vector format in arcmap. A constant was created in the form of a 5 X 5 grid for direct comparison over the time period. The grid was then intersected with the study area shapefile to produce separate boundaries for further analysis (figure 4.3). This grid file was then intersected with each of the landuse layers. The following is a summary of the methods for land use:

1. Obtain relevant Landsat data from glovis.
2. Creating the NDVI of the study area.
3. Determine irrigated vs. non-irrigated agriculture by subtracting summer NDVI values from spring NDVI values.
4. Use a supervised classification to determine land use classifications.
5. Convert the raster into a vector format for further analysis.

To determine continuity of irrigated areas, the irrigated area, as well as the area of each grid polygon was calculated. The sum perimeter of all features within each grid polygon was also calculated. Irrigated agriculture percentages was derived by dividing the irrigated area of each grid polygon by the total area of each polygon in the grid. The next process was to obtain the continuity index of irrigated agriculture, which is a measure of landscape fragmentation. According to Vogelmann (1995), the natural log of sum irrigated area per grid polygon divided by the sum of all linear features within a grid polygon is an estimate that is used to obtain continuity.

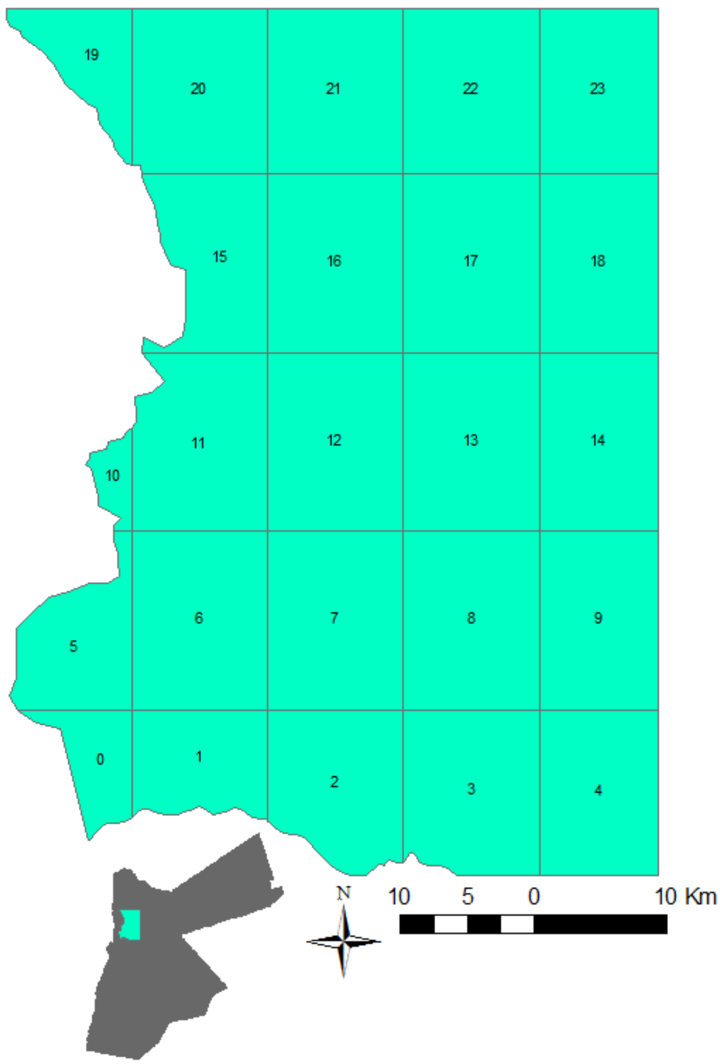



**Figure 4.4:** Grid polygon created for continuity calculation within the study site.

## Chapter 5: Results

### Likert Survey Results

Generally speaking, the respondents being interviewed were helpful and friendly, but some did show hesitation in answering questions pertaining to income. There was a small number of people that were uninterested or too busy to be able to participate. The results of the study give a number of insights to the population of Jordan. Overall, the respondents that participated in the survey were young, educated at a high school level and were employed. Most were married and earned an income below the $15,000. A number of cross tabulations between the demographic data were also examined in order to discern basic relationships of the different factors.

Sex was one of the demographic questions that was addressed. Administering questionnaires to females proved difficult at times due to the conventional Muslim social taboo of cross-gender interactions. In many cases a male relative would bring a survey to a female relative where she would then complete it. Overall, 33% of the participants were female, while 62.5 were male, and 4.5 did not respond. Of the females that responded, the majority hailed from Amman and Madaba (table 5.2). In the case of Amman, male-female interactions are more common than in outlying villages due to the urban nature of the city, where it is not uncommon for women to hold professional positions in the workplace. Madaba, on the other hand, has a larger Christian population percentage wise and the taboo was not as apparent as it is in predominantly Muslim villages.

The next question on the survey addresses land ownership. The majority, 38.4%, owned land for more than 10 years. This is quite common in the Middle East as land mainly passed through inheritance. The increase of land sold between 1 and 4 years was attributed anecdotally to the influx of rich Iraqis that were able to invest in real estate.

A slim majority, 46%, of respondents were married, followed by 39.3% single and 14.3% widowed. The majority of respondents were 26-30 year olds at 18.8% followed by 21-25 year olds at 16.5%. Figure 5.1 demonstrates the relationship between age and marital status. As expected, the vast majority of respondents in the 2 lowest ranges of age are single.

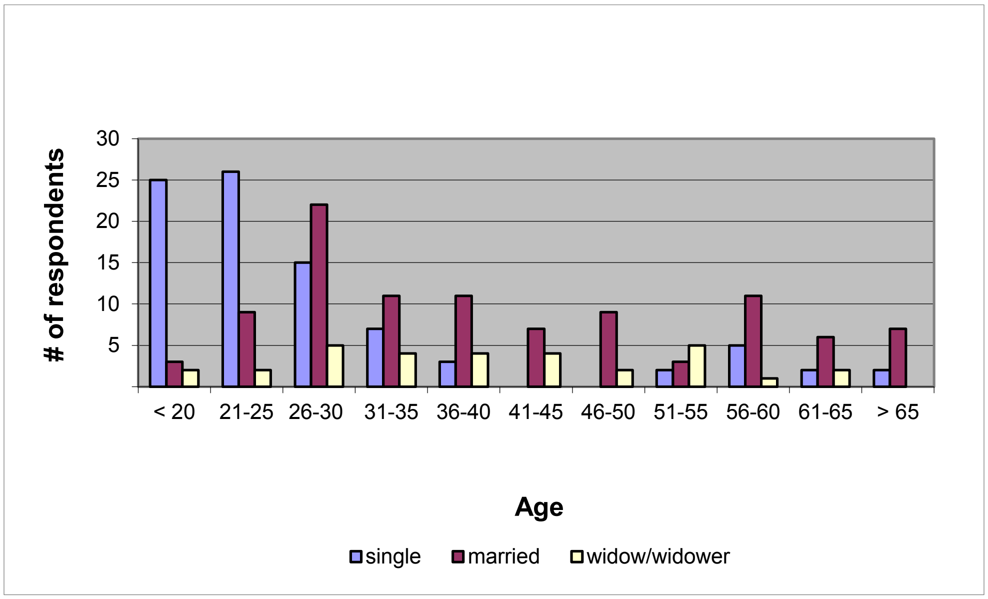



**Figure 5.1:** Age/Marital Status

It must be noted that in many cases participants were hesitant about answering the question pertaining to income until they were asked politely to include it in their answers. Figure 5.2 shows the results for all demographic questions. Overall, 13.4% of all respondents refused to answer this question, even after assurances that it was for an educational study. Falsified or non existent responses to certain types of data such income and water usage are not uncommon and are often due to fears of government actions toward the respondent (Al-Adamat et al 2004). Of those that responded, the majority 56.2% had an income of less than $15,000. Only one respondent claimed to have an income of over $30,000.

The majority, 48.2%, of respondents completed high school, followed by 14.3% of “some college”. This category includes both people still in college as well as people that had to discontinue their education. 10.3% of respondents stated that they had either a Masters or a Ph.D. The majority, 21.4%, of those who responded about employment describe themselves as working for a Public Agency, followed by 18.8% who claim to be self employed. Respondents describing themselves as “managerial” had the lowest totals that amounted to 6.7%.

Participants from Amman were the majority of respondents with 29.9%, followed by respondents from the region of Um al-Baseteen at 27.2%, and Madaba was the third largest represented region with 20.1% of respondents originating from there. Ma’ein, a village located near Madaba and consisting mainly of Bedouins, represented 11.2% of responding participants.

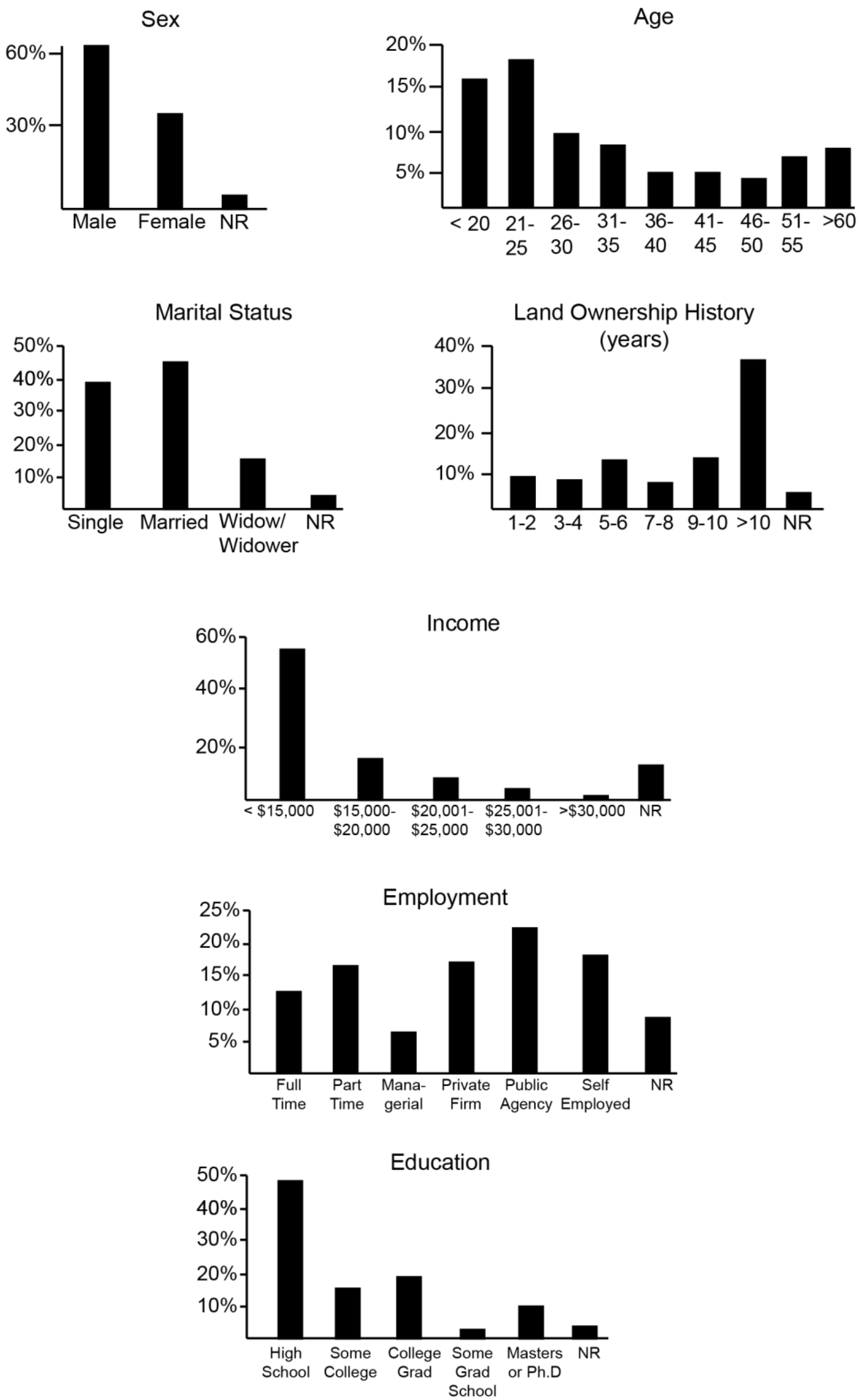



**Figure 5.2:** Results from the demographic portion of the questionnaire. Table formats can be found in Appendix G.

| **Table 5.1:** Location * Gender Crosstabulation | | | | |
|---|---|---|---|---|
| | Location | ***Female*** | ***Male*** | ***Total*** |
| | Al Khatabeyah | 0 | 2 | 2 |
| | Amman | 23 | 39 | 62 |
| | El Aarish | 1 | 4 | 5 |
| | El Faysaleyah | 1 | 3 | 4 |
| | El Mareesh | 0 | 2 | 2 |
| | El Team | 1 | 1 | 2 |
| | Lib | 1 | 1 | 2 |
| | Ma'ein | 8 | 17 | 25 |
| | Madaba | 19 | 24 | 43 |
| | Madaba/Ma'ein | 0 | 1 | 1 |
| | No Response | 3 | 3 | 6 |
| | Um Baseteen | 17 | 43 | 60 |

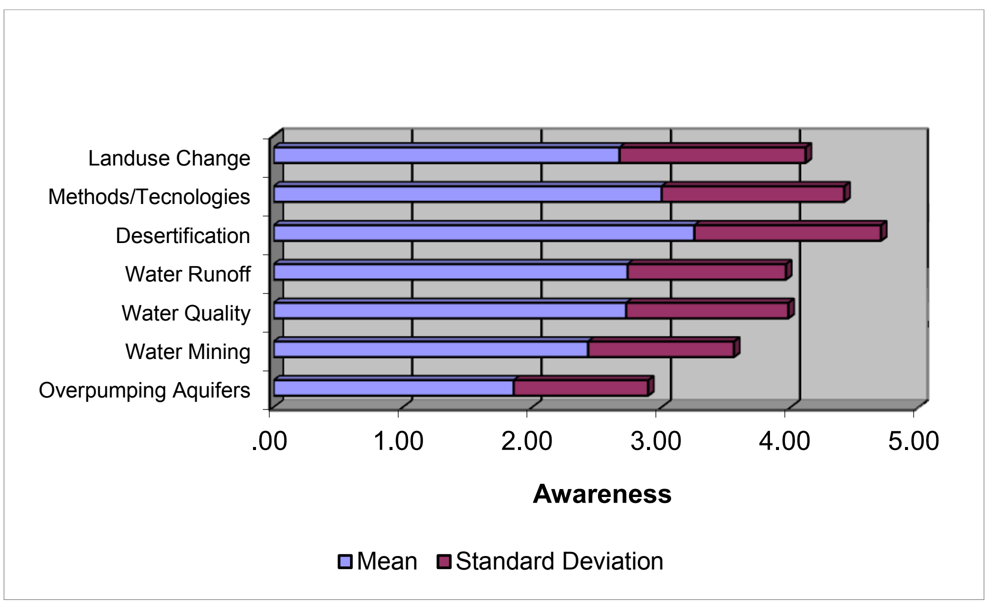



**Figure 5.3:** Mean Awareness Rating

Very few people were aware of the issue of over pumping aquifers for agriculture. 46.9% of the respondents answered “Not Aware” and 31.7% were somewhat aware. Out of the seven Likert questions administered (Figure 5.3) the mean of this particular question had the lowest mean at 1.86 and had a standard deviation of 1.04. The relatively high standard deviation suggests that answers to this questions were located more at the extreme ends of the data. This suggests that the study population either really understands the phenomena of overpumping aquifers or doesn’t understand it, with not much of a middle ground. This relatively large standard deviation also suggests that the 8.5% of the very and strongly aware category are more then one standard deviation removed from the mean, which may make these respondents outliers in the study.

Awareness about water mining did not fare much better with 21.9% “Not Aware” and 35.3% “Somewhat Aware”, as can be seen in figure 5.4 which shows all results for Likert scale questions. However, the mean for this topic was substantially better at 2.43 with a standard deviation of 1.13. Although still high, the standard deviation suggests that most respondents answered closer to the mean, which could mean that respondents were less extreme in their awareness for this particular issue relative to the question of overpumping of aquifers. Again, the percentage of respondents that place out of one standard deviation are those that answered very and strongly aware at a combined 18.3%.

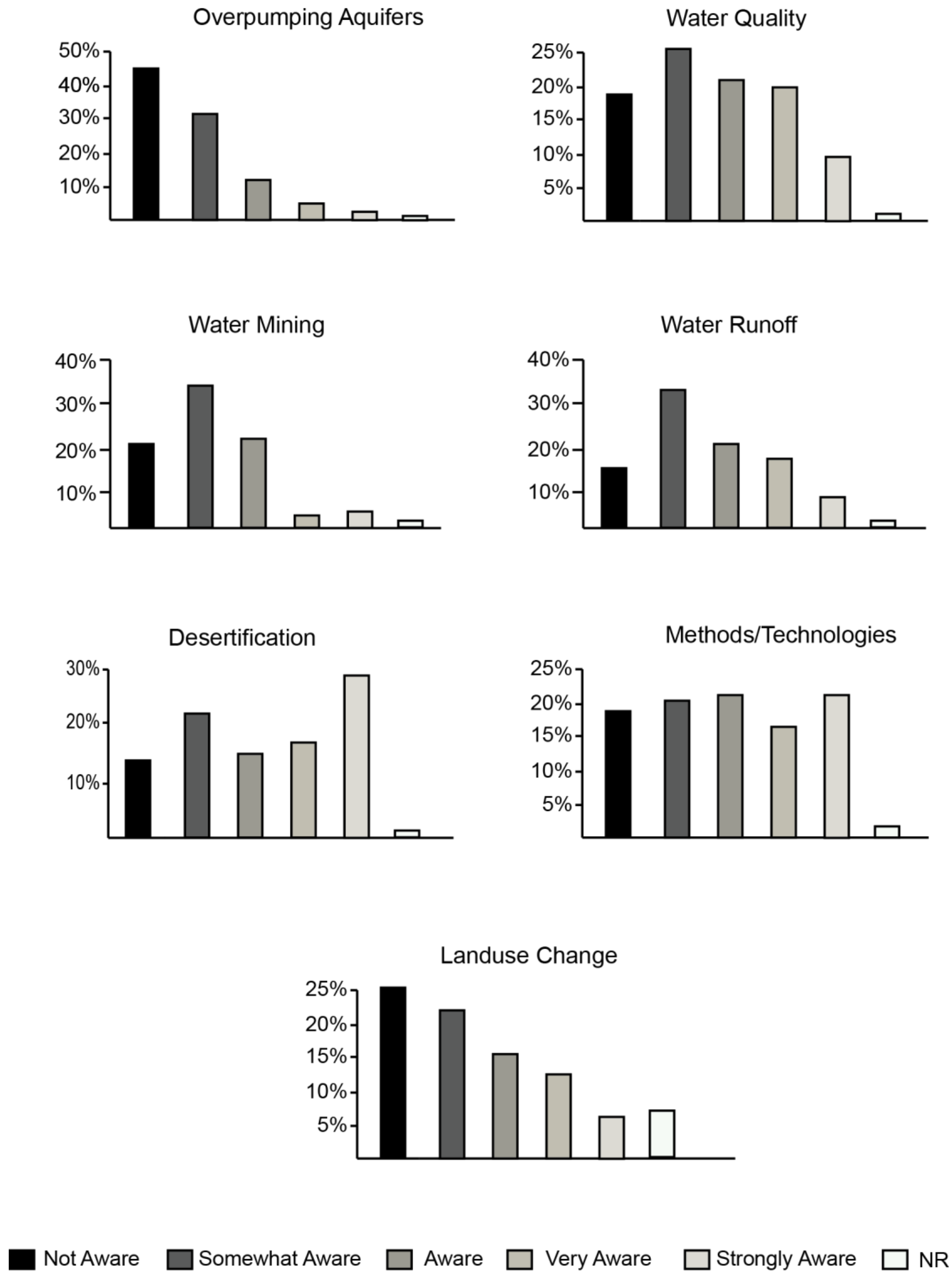



**Figure 5.4:** Results from the Likert portion of the questionnaire. Table formats can be found in Appendix G.

Overall Water quality awareness improved slightly over the previous 2 catagories, with 19.6% being “Very Aware” and 9.4% being “Strongly Aware”. However, the majority of people, 26.8%, were only “Somewhat Aware”. There was a mean of 2.73 and a standard deviation of 1.25 that reflects this increase in awareness. The data is also relatively more localized around the mean which again suggests that the responses to the survey were not as variable relative to the overpumping questions.

The vast majority, 33%, of respondents where only “Somewhat Aware” of Water Runoff issues, while 15.6% were “Not Aware”. The mean of this topic was 2.74 with a standard deviation of 1.22. On the issue of Desertification, 29% of participants responded that they were “Strongly Aware”, while another 17.4% responded “Very Aware”. Again, there is localization occurring near the mean suggesting that answers given by study participants are not as variable as overpumping of aquifers.

Desertification had the highest amount of awareness. The mean of desertification was 3.25 and the standard deviation was 1.45. 29% of participants were strongly aware, while 17.4% were very aware. Because the standard deviation is small relative to the mean, the participants responses are not as variable. This would suggest that most participants have at least some knowledge in relation to desertification.

There was an even spread of responses on the issue of methods and technologies for preventing water loss. This category had the second highest mean at 3 with a standard deviation of 1.42. 21% were “Strongly Aware”, 16.1% were “Very Aware”, 21.4% were “Aware”, 20.5% were “Somewhat Aware” and 18.8 % were “Not Aware”. Again, this suggests that there is a general awareness about methods and technologies and less people at the extremes of awareness.

Finally, landuse change had a mean of 2.67 and a standard deviation of 1.44. 25.9% of respondents were not aware of any changes in landuse on their plot of land. 23.2 % responded that they were somewhat aware. The mean of this category was 2.67 and the standard deviation was 1.44. The variability of participant responses is relatively high in this case, but still lower than the issue of overpumping.

The overall trend of the data seems to be that variability in awareness is high, and that the respondents either are aware or not with not much middle ground with the exception of perhaps the questions on desertification and methods and technologies.

**Aquifer and Landuse Change Results**

The results of the ground water depth maps showed a large variability for each of the years in the study (Figures 5.5-5.8). There was a positive change that occurred in the north near Amman, while the negative changes occurred in the east, in the area of the desert. In regards to the area of Amman, this is somewhat surprising considering that an urban center should have higher demand for localized water.

Changes between 1986 and 1991 are relatively low. The largest decline occurs in the south central region with a maximum decline of 14.1 m. There is a gain of approximately 5 m in the Amman area. The time period between 1991 and 1998 shows much more fluctuations in water depth levels. The significant gains (up to 60 or more meters) take place in the Amman region, as well as the very south central portion of the study area near the village Dhiban. The largest decrease takes place east of Amman towards the desert region where a 50m decrease has been measured. A decrease of approximately 5-6 meters is taking place in the central area of the study area. The time period between 1998 and 2002 shows a significant overall decrease in water levels, with the exception of Amman which demonstrates a slight increase of approximately 5 m.  The region near Madaba shows a massive decrease of up to 75 m.  The region around Dhiban also decreases by approximately 60 m.  The region southwest of Amman also decreases approximately 70 m.

Finally between 2002 and 2007, a slight increase of 1-2 m occurs in the Amman Area.  A much larger increase of approximately 30 m occurs southeast of Madaba.  The greatest decreases of approximately 20 m again occur southwest of Amman, and again near Dhiban. Positive gains in the urban area of Amman may be attributed to municipal water use getting recycled and reintroduced into the underlying aquifer system, and may be a direct function of population increase.  Depletions in the eastern desert may be attributed to overpumping and lack of recharge from rainfall.

Overall, landuse classes were relatively unchanged in regards to location within the study area (Figure 5.9-5.12).  The north edge of the study area was dominated by the urban area of Amman, while the far majority of the east was desert.  Natural vegetation made up the majority of landuse type in both the northwest and southwest portions.  The agricultural class made up the large central swath of the study area.  This class had irrigated agriculture intermingled with it. Temporal changes in landuse are summarized by Table 5.2.

**Table 5.2:** Percentages of landuse classification per year.

| | ***1991*** | ***1998*** | ***2002*** | ***2006*** |
|---|---|---|---|---|
| Urban | 13.99968 | 13.83926 | 13.71619 | 17.48071 |
| Desert | 44.78412 | 40.19879 | 42.13862 | 42.57675 |
| Agriculture | 15.89175 | 25.40492 | 18.01933 | 18.14665 |
| Irrigated Agriculture | 3.109298 | 2.03308 | 1.622929 | 1.159065 |
| Natural Vegetation | 22.21515 | 18.52396 | 24.50292 | 20.63682 |

The desert class was the most prevalent in the study area ranging between 40 to 44%. Both natural vegetation and non-irrigated agriculture had similar data ranges at 18.5 to 24.5 and 15.9 to 24.4% respectively. Non irrigated agriculture had the largest increase of any class at approximately 10% between 1991 and 1998. The year 1991 had the most irrigated agriculture of all times at 3.1%. Changes in this class were most prevalent near Madaba (figure 5.9). There was a decreasing trend throughout the time frame of the study. The greatest decrease took place between 1998 and 2002 were total area of irrigated agriculture decreased by about 1.4%. There was approximately .5% difference in irrigated agriculture between 2002 and 2006.

A significant issue of the increase of urban areas is the amount of surface area that is covered by asphalt and concrete. This in turn reduces aquifer recharge from precipitation. Another phenomena associated with urban areas is the high quantity of runoff that is prevalent. Due to the nature of urban areas, higher concentrations of pollutants may be present in the runoff, that will either pool up and evaporate or filter down into the aquifer system.

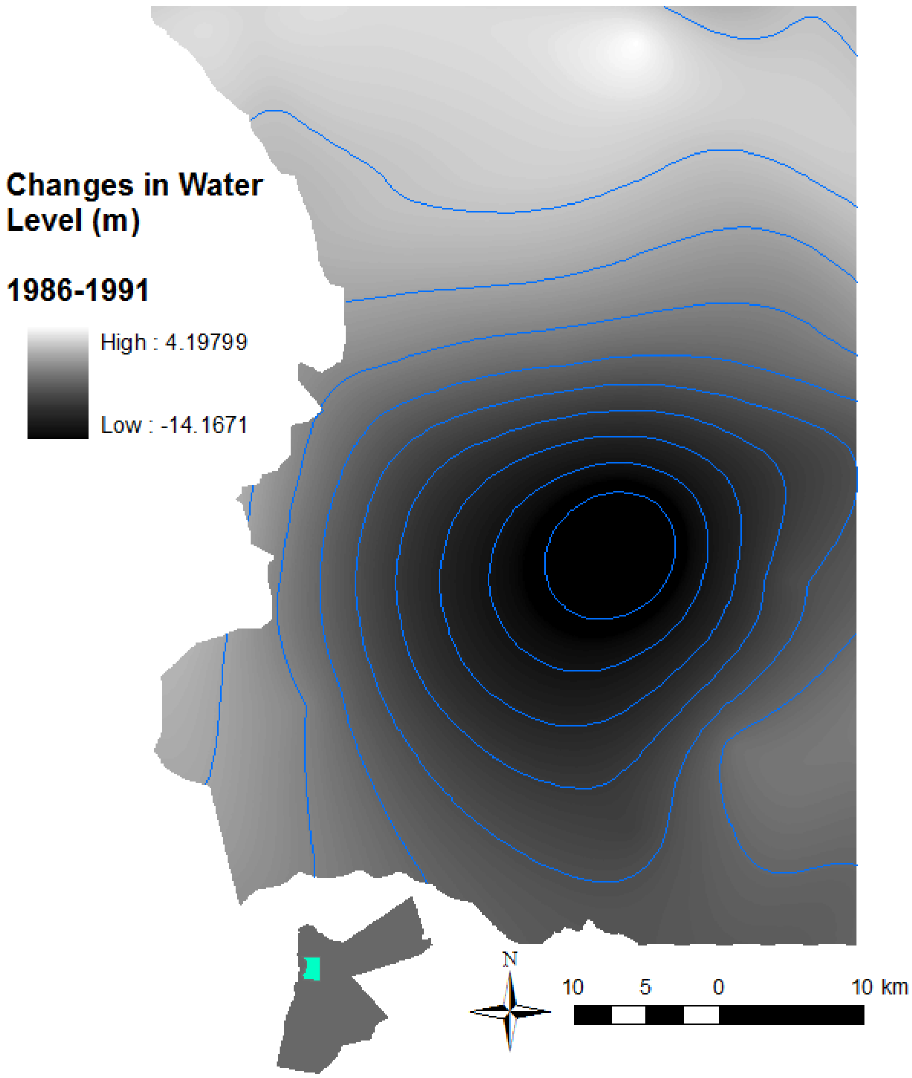



**Figure 5.5:** Changes in water depths for 1986 to 1991. The Jenks classifications are overlaid to show the extent of Jenks ranges.

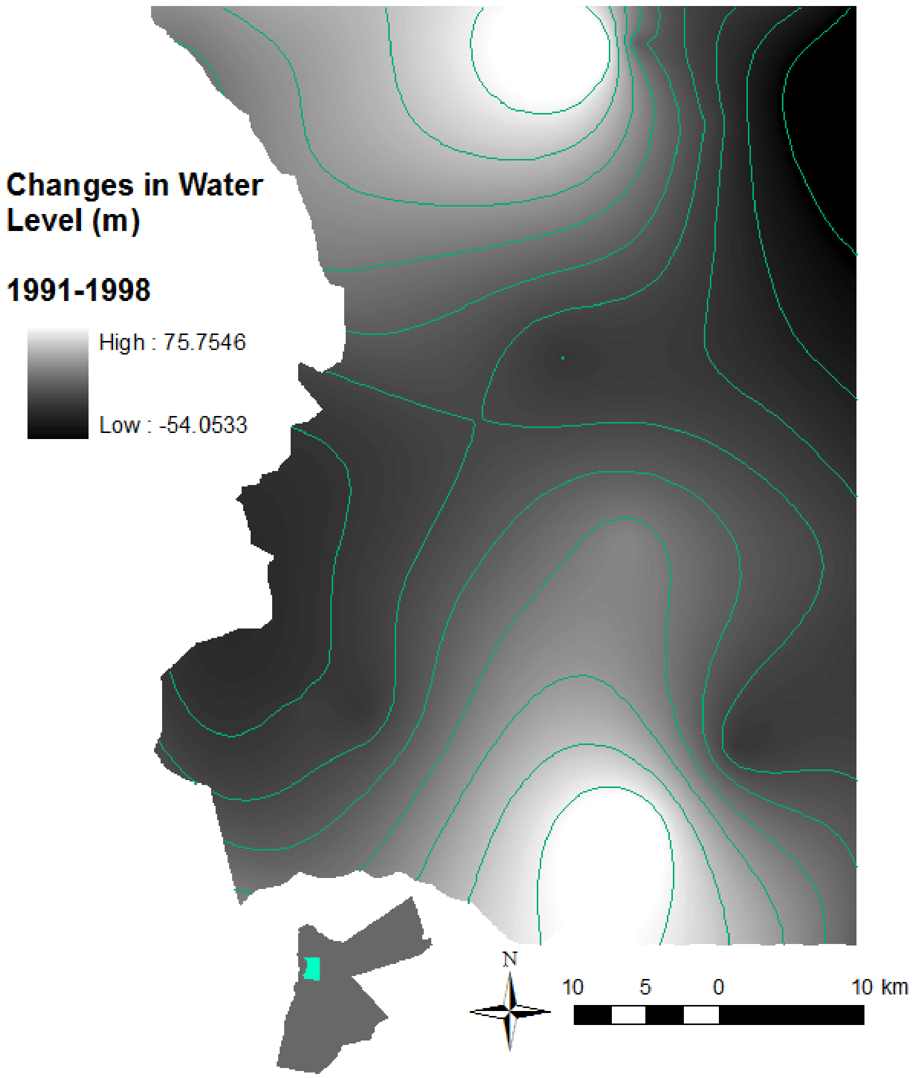



**Figure 5.6:** Changes in water depths for 1991 to 1998. The Jenks classifications are overlaid to show the extent of Jenks ranges.

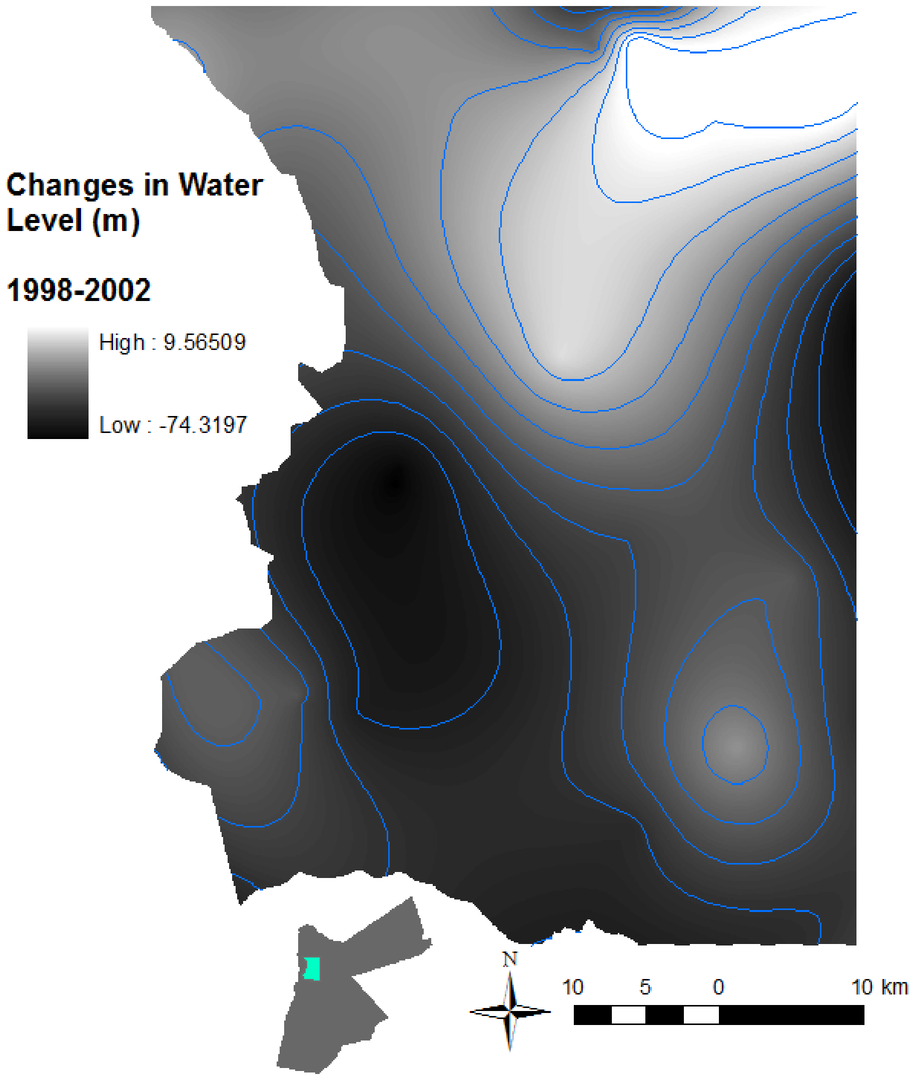



**Figure 5.7:** Changes in water depths for 1998 to 2002. The Jenks classifications are overlaid to show the extent of Jenks ranges.

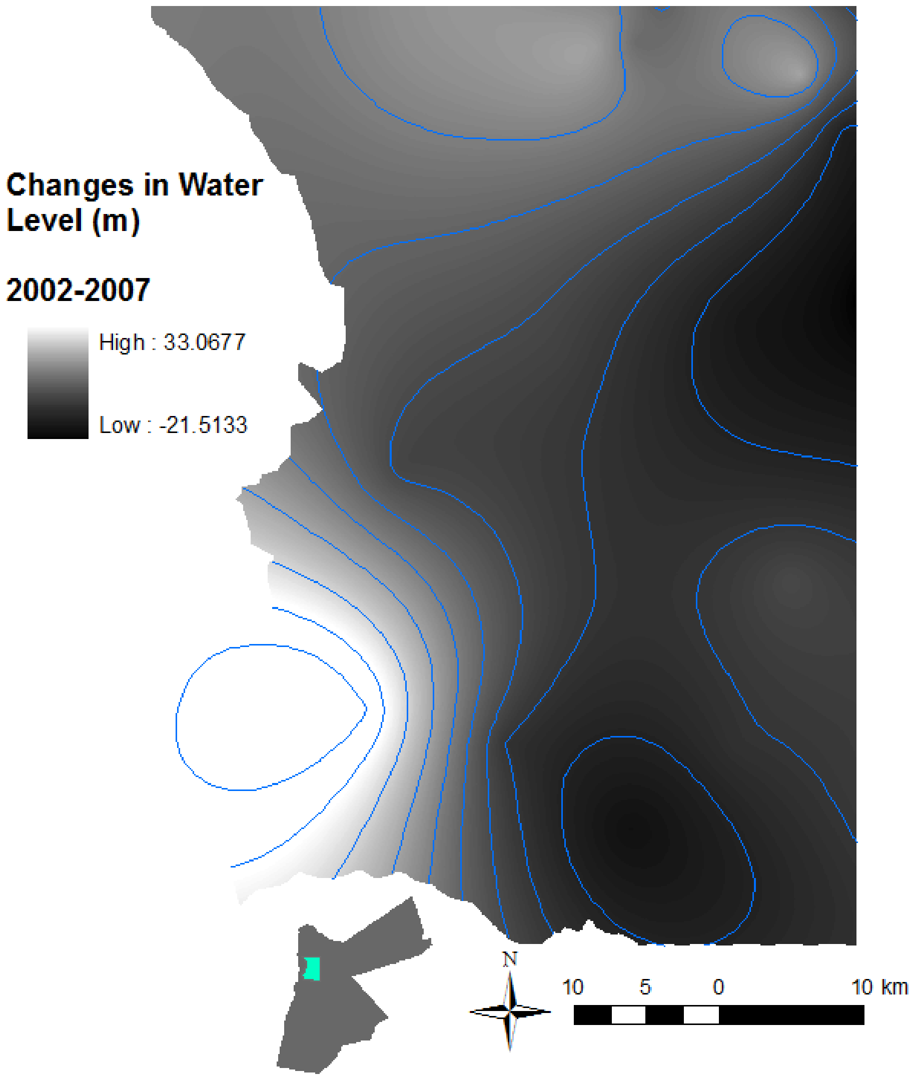



**Figure 5.8:** Changes in water depths for 2002 to 2007. The Jenks classifications are overlaid to show the extent of Jenks ranges.

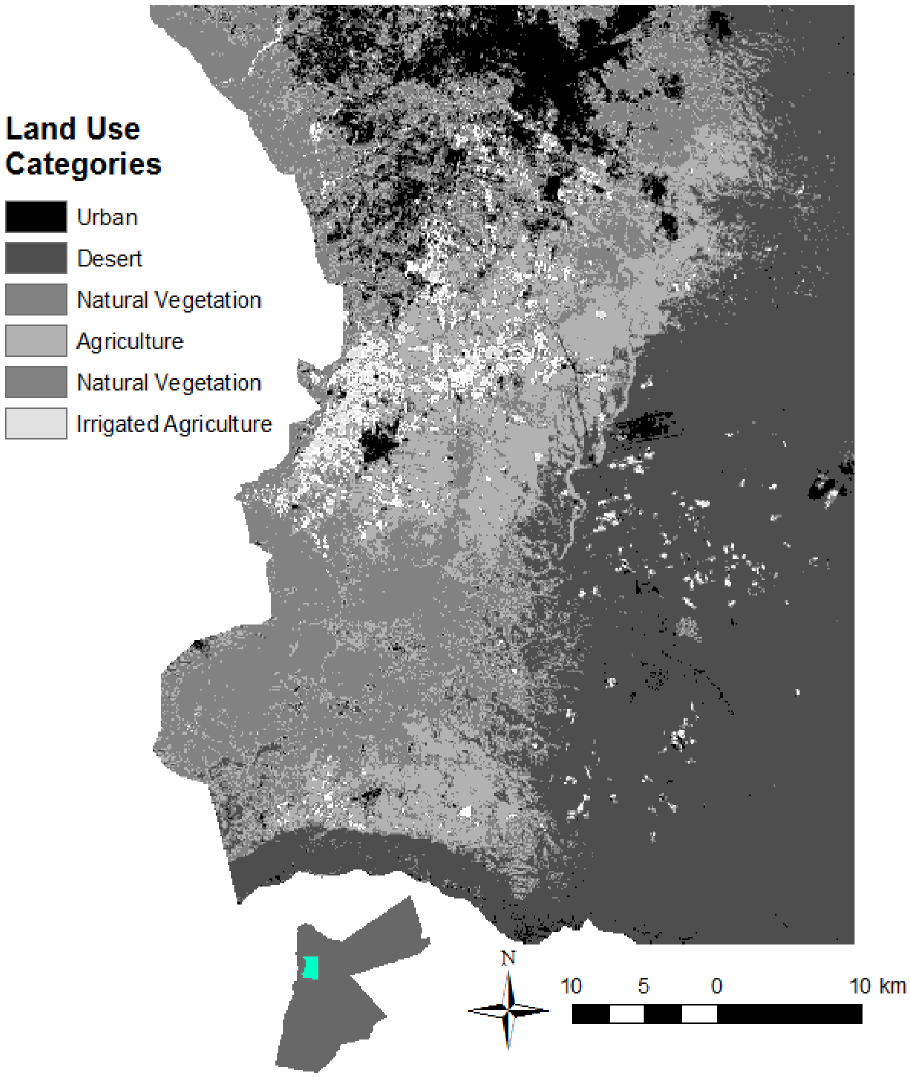



**Figure 5.9:** Landuse for 1991

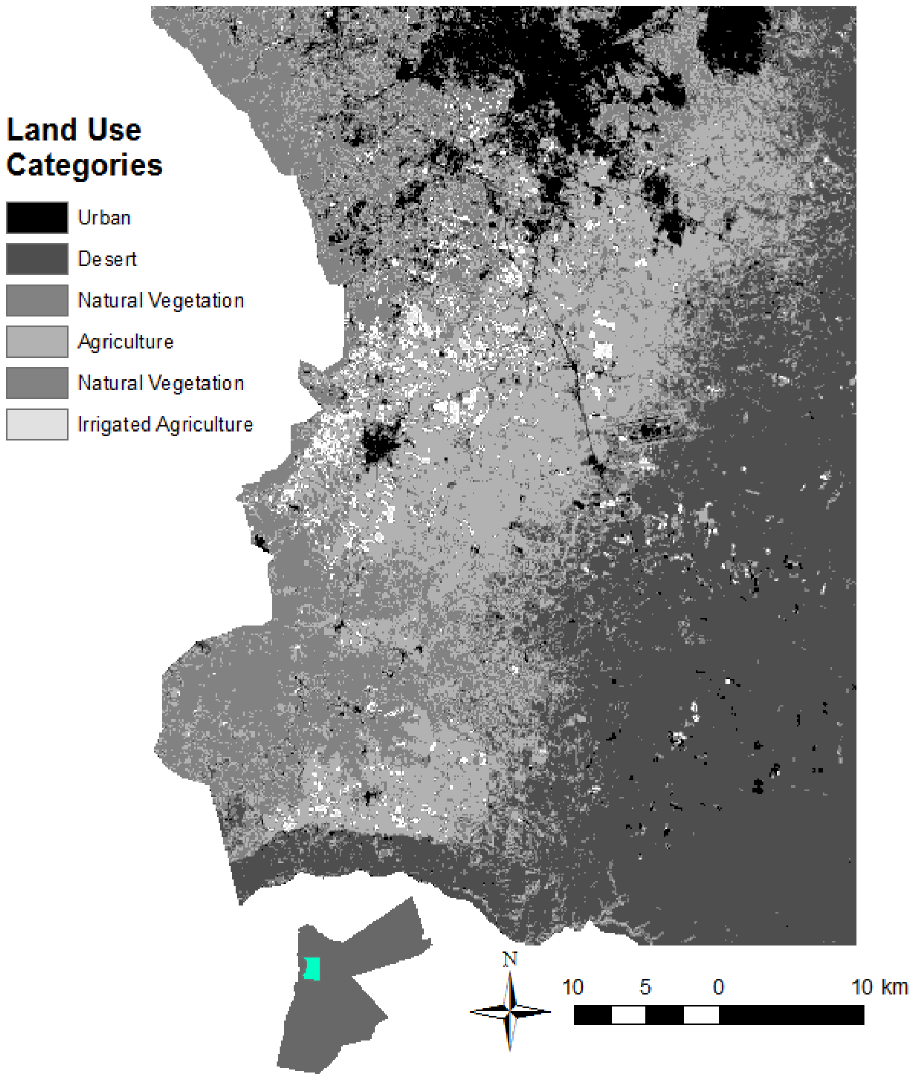



**Figure 5.10:** Landuse for 1998

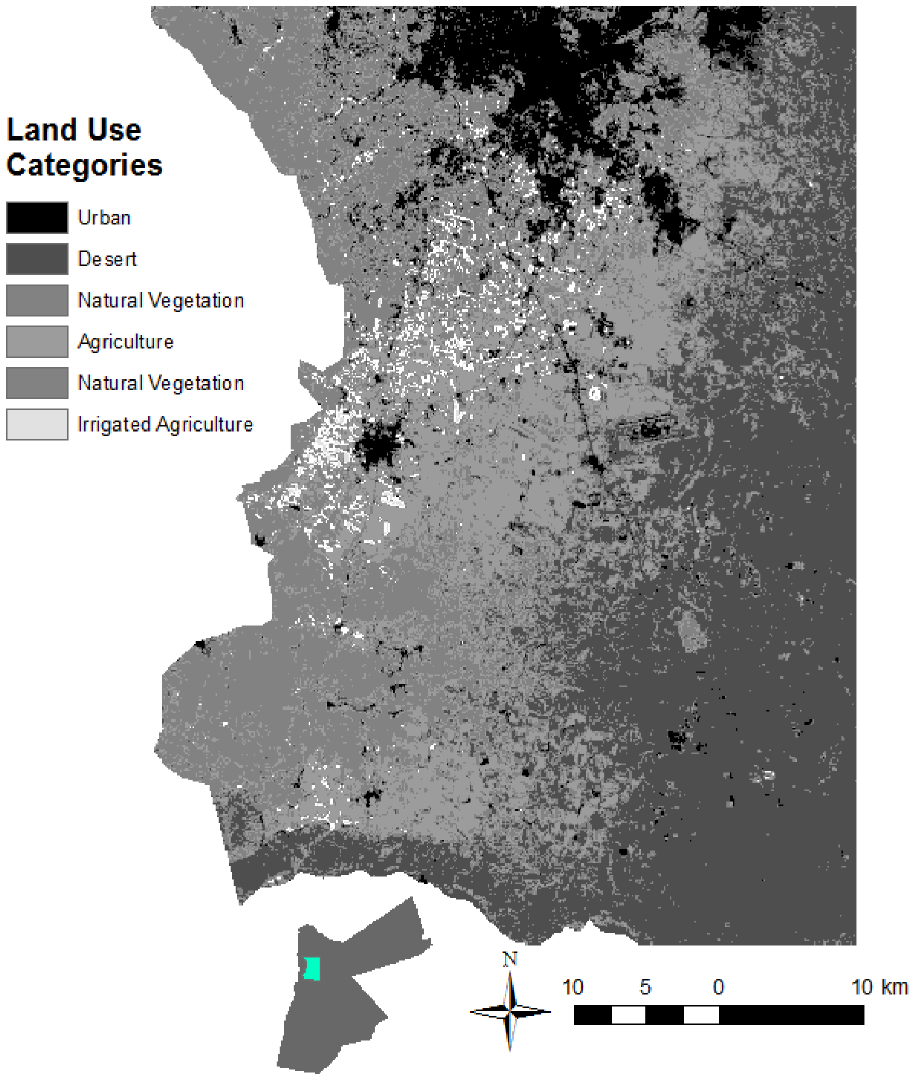



**Figure 5.11:** Landuse for 2002

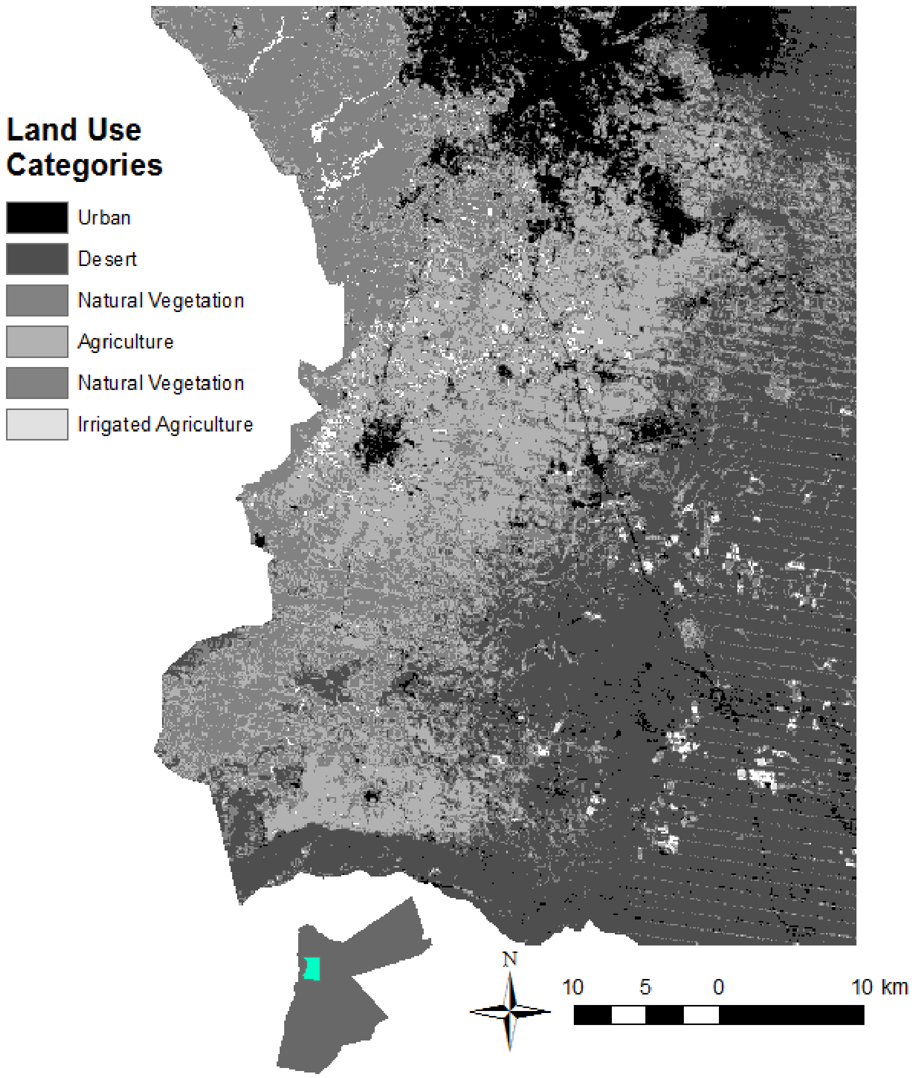



**Figure 5.12:** Landuse for 2006

## Chapter 6: Discussion

### Analysis: Correlations and Crosstabulations

Although Pearson"s R values are more reliable and can produce a coefficient of determination, Spearman"s Rho correlations were administered due to the ordinal nature of the variables with a two-tail significance test (Meyers and Well 2003). There were a number of significant relationships found between the demographic questions and the Likert scale questions. A positive correlation was found for land ownership and awareness of desertification at r = .231 at the .01 significance level. A closer look at the crosstabulation (figure 6.1) reveals the actual relationships between the different variables.

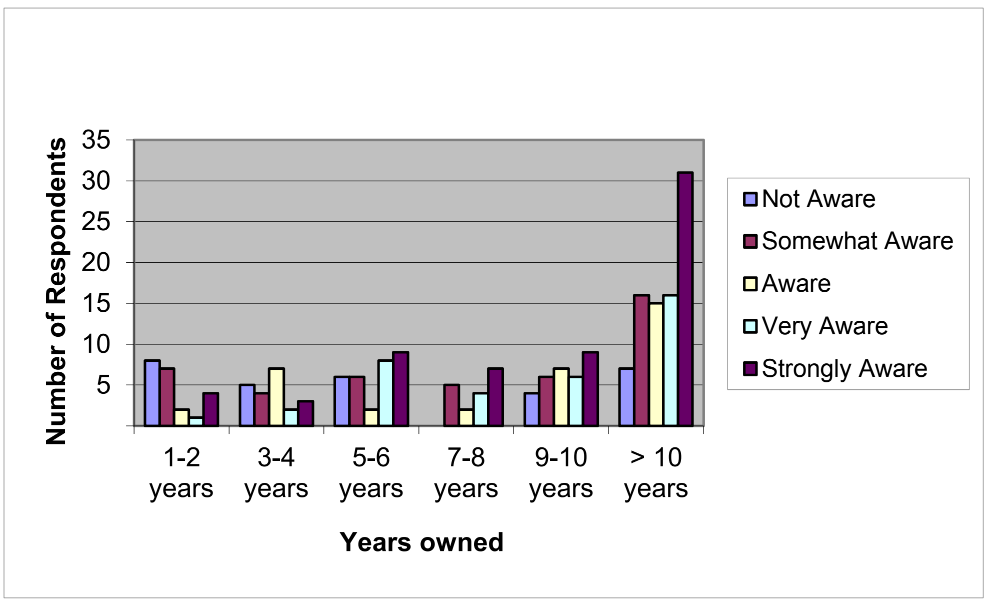



**Figure 6.1:** Crosstabulation of land ownership and desertification.

As can be seen, the overall trend for all levels of awareness is relatively stable. The exception occurs at the mostly aware and the > 10 years category where 36% of respondents placed.  Another correlation occurred between land ownership and methods/technology with r = .228 at .01 significance (figure 6.2).  Again the numbers of respondents in the very/strongly aware categories outnumber the not/somewhat aware 40 to 26 for respondents that have owned land over 10 years.  The third and final crosstabulation that Land ownership demonstrated was a significant correlation to land use change where r = .256 at the .01 significance level (figure 6.3). In this case, the crosstabulation shows a marked increase in the lower level of awareness in the lower levels of land ownership.

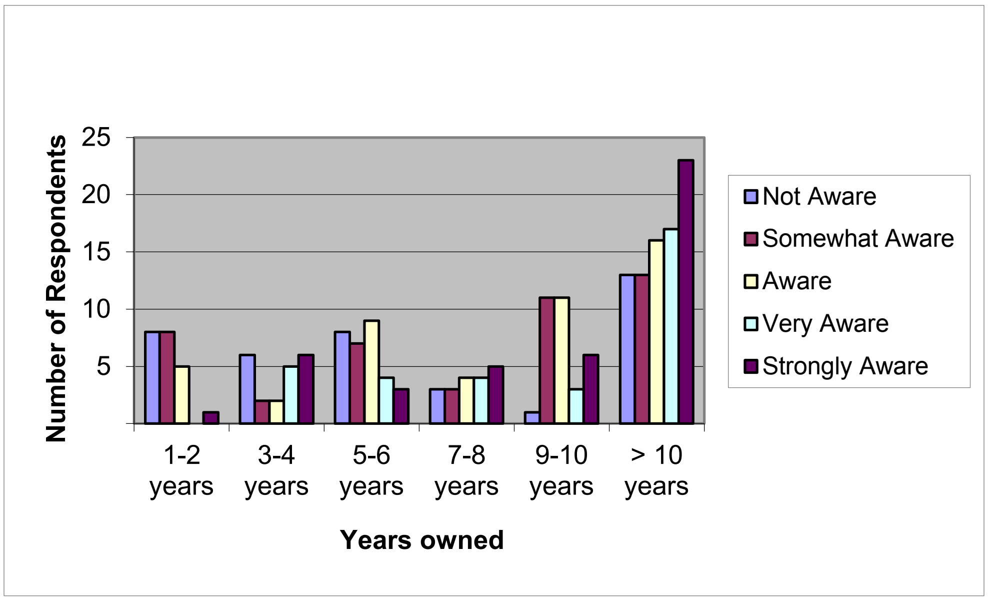



**Figure 6.2:** Crosstabulation of land ownership and

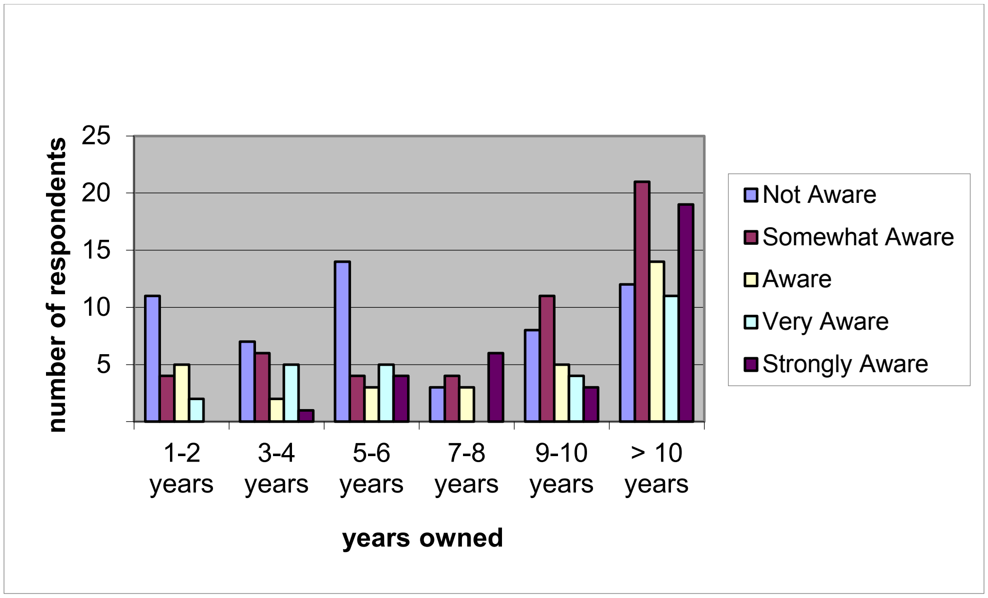



**Figure 6.3:** Crosstabulation of land ownership and land use change.

Income group and age groups were slightly correlated with r = .185 at .01 significance. This follows the logic that the older the age, the more experience gained and therefore the salary is higher for a particular respondent. Similarly income and education correlated with r =.296 at .01 significance. Again, the higher the education, the higher the pay scale for a respondent. Income plays a minor role in awareness pertaining to the different variables. Income and water quality awareness correlated at r = .156 at .05 significance. Figure 6.4 shows the number of not aware and somewhat aware are extremely well represented in the < $15,000 range, as a total of 71 respondents were represented.

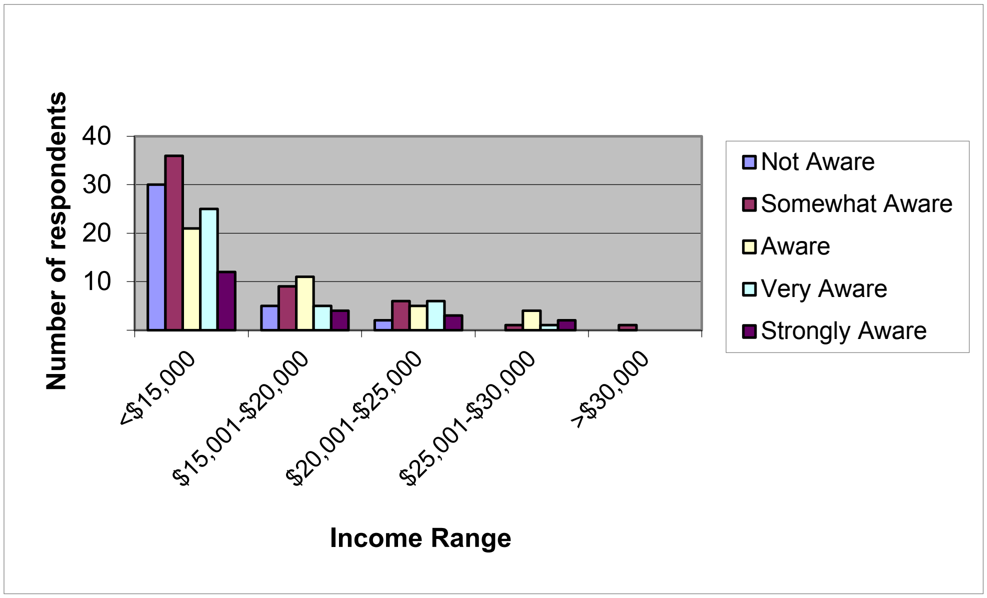



**Figure 6.4:** Crosstabulation of income and water quality.

Similarly, income and water runoff also had a slight correlation with r = .231 at .01 significance. Figure 6.5 again demonstrates the lack of awareness in the lower income levels. In this case, the number of respondents that answered non to somewhat aware was a total of 69. In both the aforementioned cases the overall percentage of awareness increased as the pay range increased.

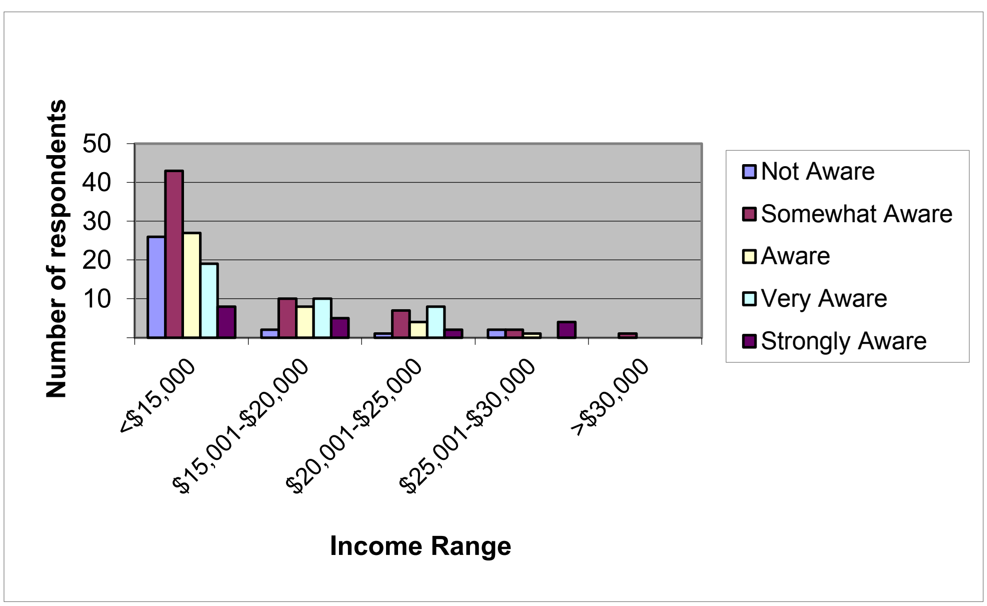



**Figure 6.5:** Crosstabulation of income and water runoff.

Age and education correlated with $r = .192$ at .01 significance. This low r value indicates that age does not have much of an effect on the level of education. Age and methods/technologies correlated well with $r = .362$ at .01 significance. This relatively high correlation suggests that adaptability increase with age and experience. Figure 6.6 expresses the trend. In the <20 to 25 age groups, the number of not and somewhat aware respondents was 49%, whereas at the older age groups had a larger percentage that were more aware. Age and land use change were less correlated with $r = .258$ at .01 significance. Figure 6.7 shows that the trend is most visible in the younger ages and seems to level out as age increases. 44% respondents in the < 20 to 25 age group responded as not or somewhat aware.

Surprisingly, the relatively high correlation of age and methods and technologies is opposite of a similar culture dealing with a different hazard. A prior study by Paradise (2008) indicated that new technologies in dealing with building earthquake resistant structures were deemed safer by younger respondents as opposed to older participants. This is counter to the results that show older respondents had responded with a higher percentage of “strongly aware”. This discrepancy may be due to the types of hazards involved. Technologies that deal with water or agriculture may be relatively more important than those of seismic risk due to the daily need for these items, whereas seismic events do not occur very often.

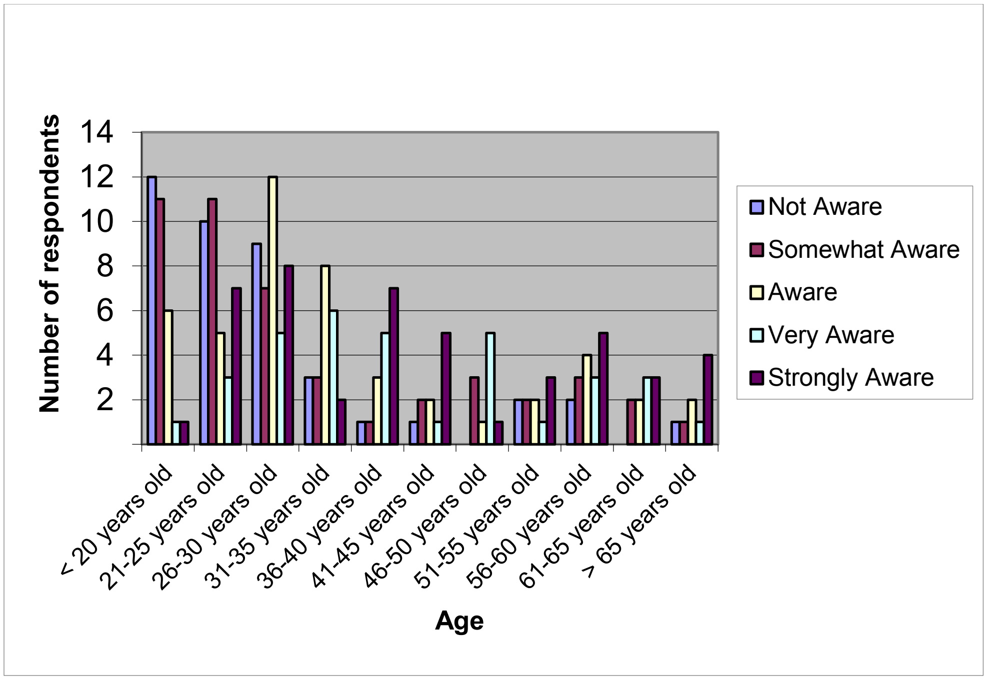



**Figure 6.6:** Crosstabulation of age and methods/technologies.

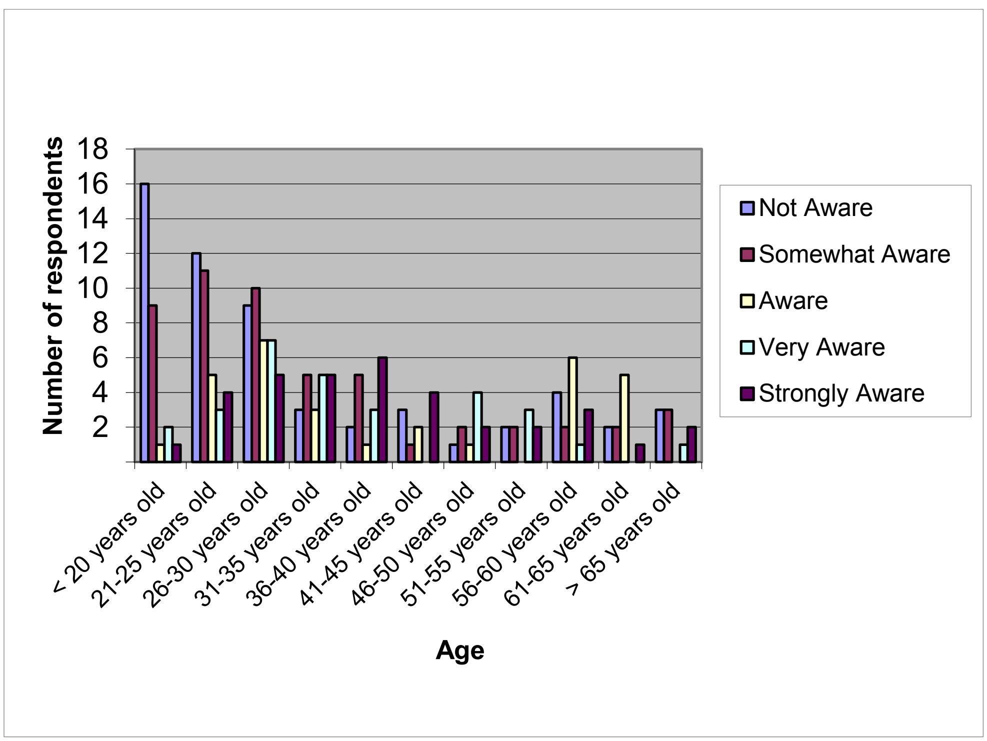



**Figure 6.7:** Crosstabulation of age and land use change.

Some of the higher correlations in this study included education as one of the variables. Education and water mining correlated with r = .318 at .01 significance. As figure 6.8 shows, 61% of people that only have a high school education answered not or somewhat aware of water mining. As education increased, a higher percentage of the total respondents are aware of water mining issues. Similarly education and water runoff correlated with r = .301 at .01 significance (figure 6.9). In this case, 60% of people educated up to the high school level replied not or somewhat aware. Education and desertification correlated with r = .194 at .05 significance while education and land use change correlated with r = .208 @ .01 sig. The implication here is that both water mining and water runoff are actively being discussed in academic settings, and that desertification and land use change are not discussed as much.

This research supports a prior study by Paradise (2008) that demonstrates how education can affect the nature of forecasting, predicting, and related mitigation of a hazard. In his study, less educated respondents were more likely to reject the significance of scientific assessment and forecasting adding that a belief in divine protection was more important and effective. Paradise (2008) goes on to state that:

> "More educated respondents replied that more earthquakes were imminent (in this seismically active region), while the less educated stated that Allah protected those who were devout. The less educated were also generally averse to scientific assessment, forecasting, or new construction technologies. Such "predictive" modeling was akin to fortune-telling and believed to be *haram* (prohibited in the Qur'an or Hadith)."

The idea of religion having a basis in decision making was given anecdotally by a number of respondents when asked about awareness of a number of issues.

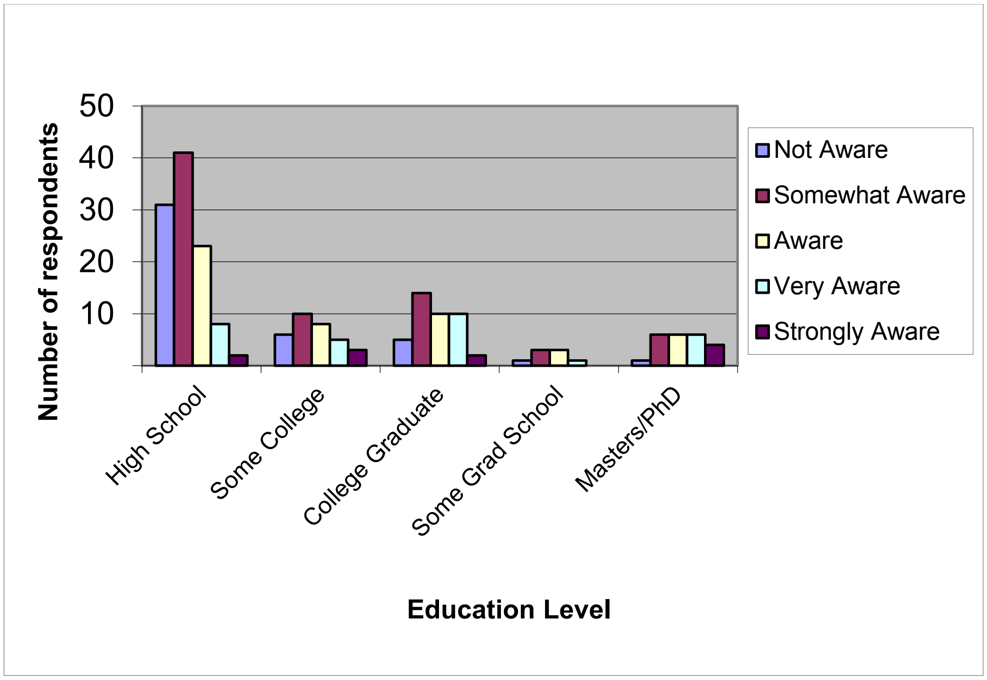



**Figure 6.8:** Crosstabulation of education and water mining.

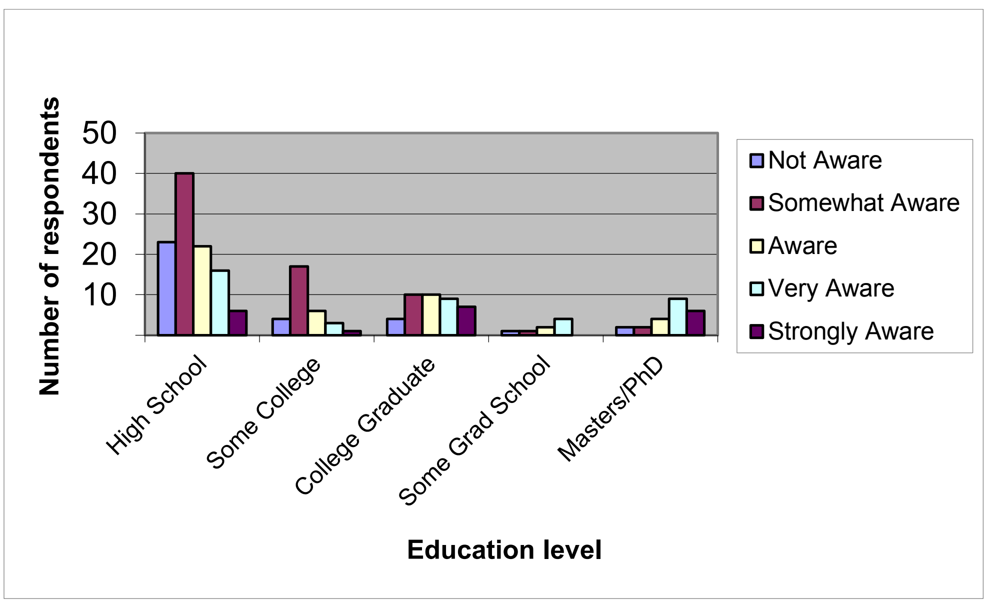



**Figure 6.9:** Crosstabulation of education and water runoff.

Spearman‟s correlations were also calculated for the Likert scale questions in relation to other Likert scale questions. Overpumping of aquifers and water mining awareness correlated with r = .327 at .01 significance (figure 6.10). 49% of all respondents were not aware or somewhat aware for both categories. The interpretation here is that respondents that were aware know that overpumping leads to water mining of the aquifer. Similarly overpumping and water quality awareness correlated with r = .295 at .01 significance. In this case, 40% of the respondents were not to somewhat aware in both categories (figure 6.11). However, the respondents that have a higher awareness seem to understand that as aquifers are depleted the water quality of aquifers decreases due to higher concentration of contaminants being left in the system (Brooks 1997). Overpumping and water runoff awareness also correlated with r = .228 at .01 significance.

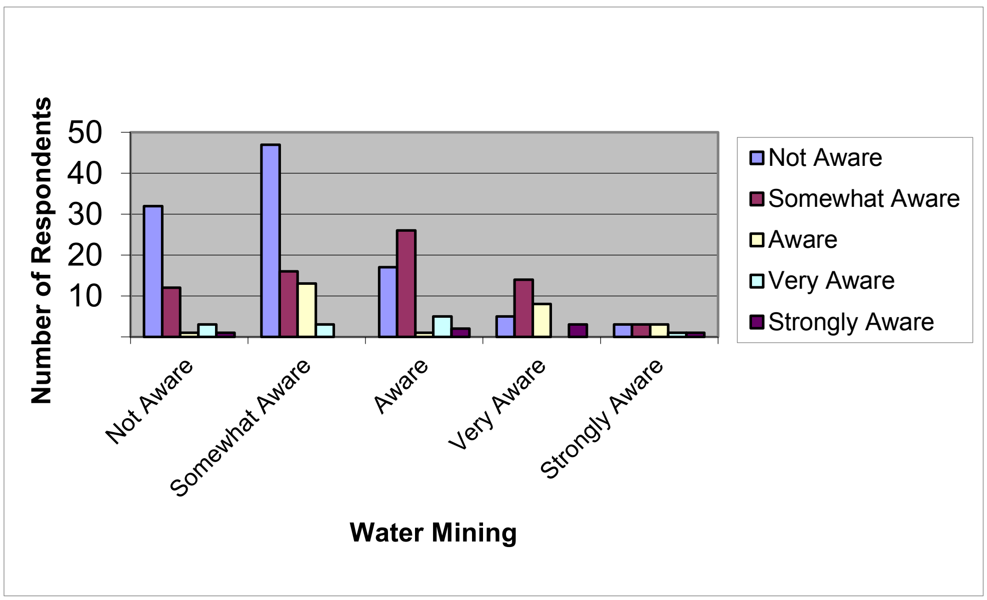



**Figure 6.10:** Crosstabulation of overpumping and water mining.

In this case, 42% of all respondents were not to somewhat aware of both categories (figure 6.12). Overpumping and methods/technologies awareness correlated with r =.252 at .01 significance where 36% of total respondents answered not to somewhat aware for both categories. At the opposite end of the spectrum, 5% answered very to strongly aware (figure 6.13). This correlation could signify the use of possible technologies that allow for the overpumping of aquifers. The final variable that overpumping correlated to was with land use with r = .206 at .01 significance, which is relatively low compared to the other variables (figure 6.14).

These figures are relatively low when compared to Sattler and Nagel"s (2010) study that demonstrated the general importance of conservation efforts in regards to groundwater in Germany. A Likert scale survey (scale of 1-5) conducted in that study showed that respondents understand that groundwater conservation efforts were very important by a mean of 4.3. This is in stark contrast to the respondents where the mean of a number of groundwater related awareness questions, particularly over pumping of aquifers, were below 3 (figure 5.2). This is especially surprising due to the fact that water is at a much higher premium in Jordan due to the scarcity.

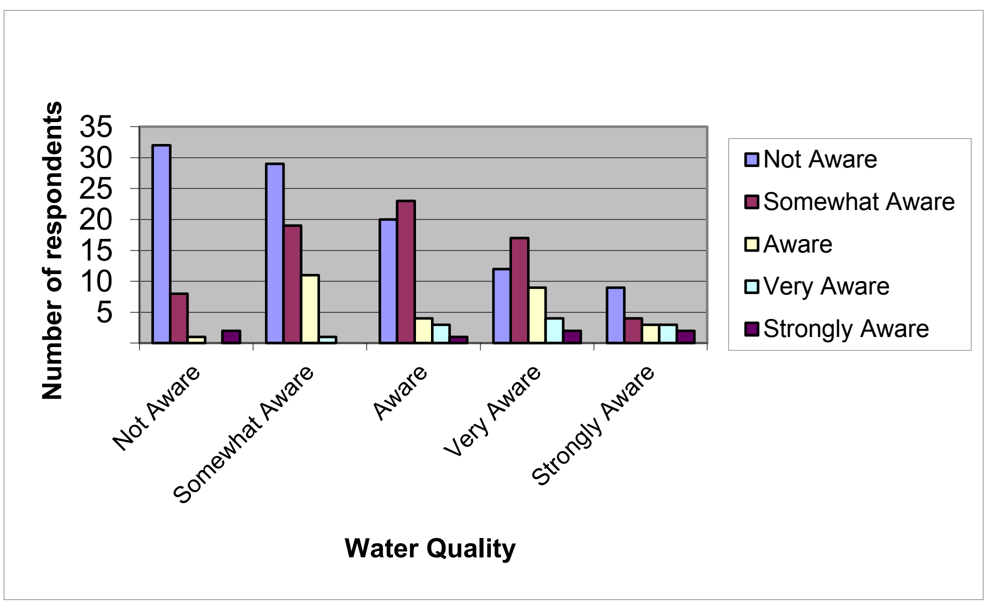



**Figure 6.11:** Crosstabulation of overpumping and water quality.

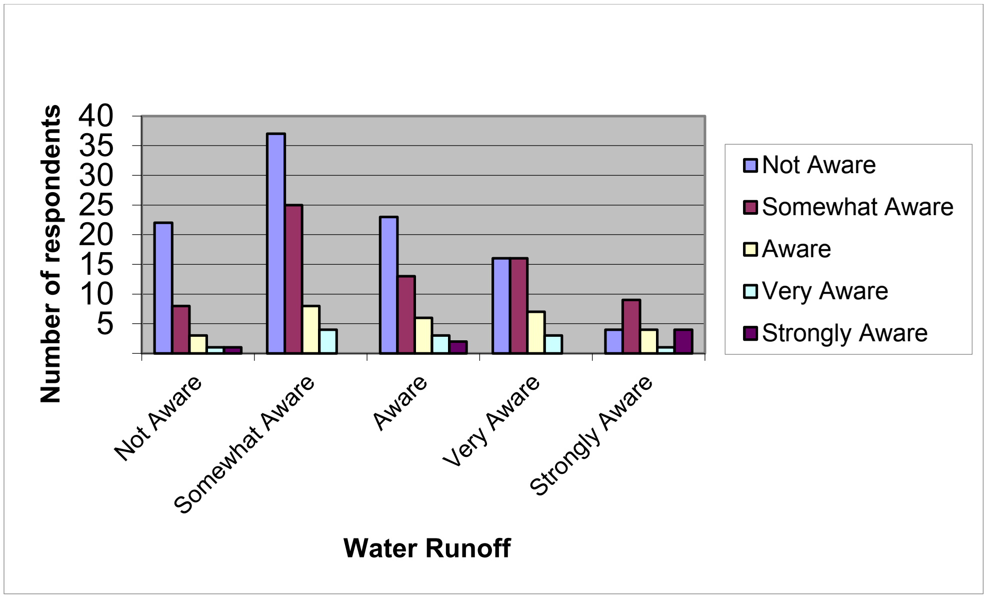



**Figure 6.12:** Crosstabulation of overpumping and water runoff.

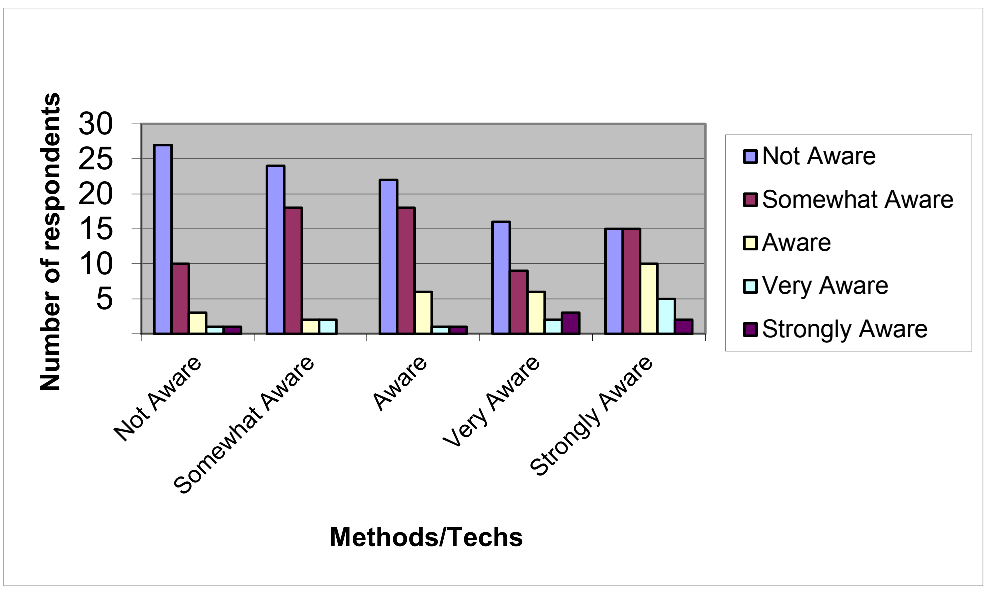



**Figure 6.13:** Crosstabulation of over pumping and

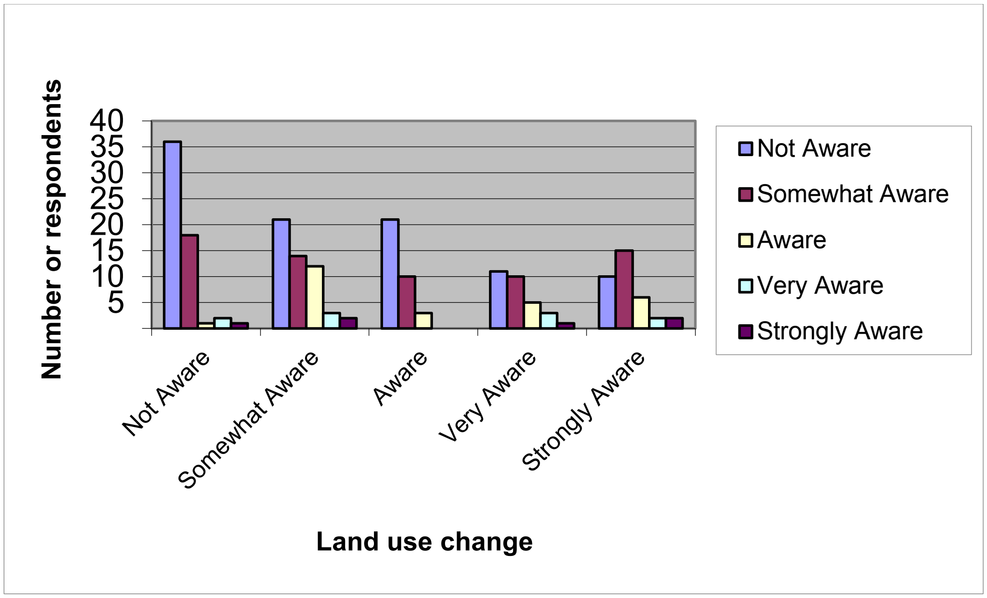



**Figure 6.14:** Crosstabulation of over pumping and land use change.

Water mining and water quality awareness correlated with r = .264 at .01 significance. This reflects the aforementioned correlations between these two variables and overpumping, due to the fact that water quality decreases with the loss of quantity. Figure 6.15 demonstrates the relationship of the two variables. The percent of respondents aware of water mining increase with the awareness of water quality. Overall, however, the number of respondents not to somewhat aware is 36% compared to 5% of those aware for both categories. Water mining and water runoff awareness correlated with r = .219 at .01 significance (6.16). In this case, the percentage of those not to somewhat aware for both categories is 33% compared to those that are very to strongly aware at 9%. Water mining and land use awareness with r = .200 at .01. This may indicate changes in land use as water is pumped from deeper within the aquifer. An example of this may be the open air reservoir ponds that are used on some farms after water is pumped (figure 6.17). 35% of respondents were not to somewhat aware for both variables, while 9% were very to strongly aware. Water mining and desertification awareness were slightly correlated with r = .169 at .05 significance.

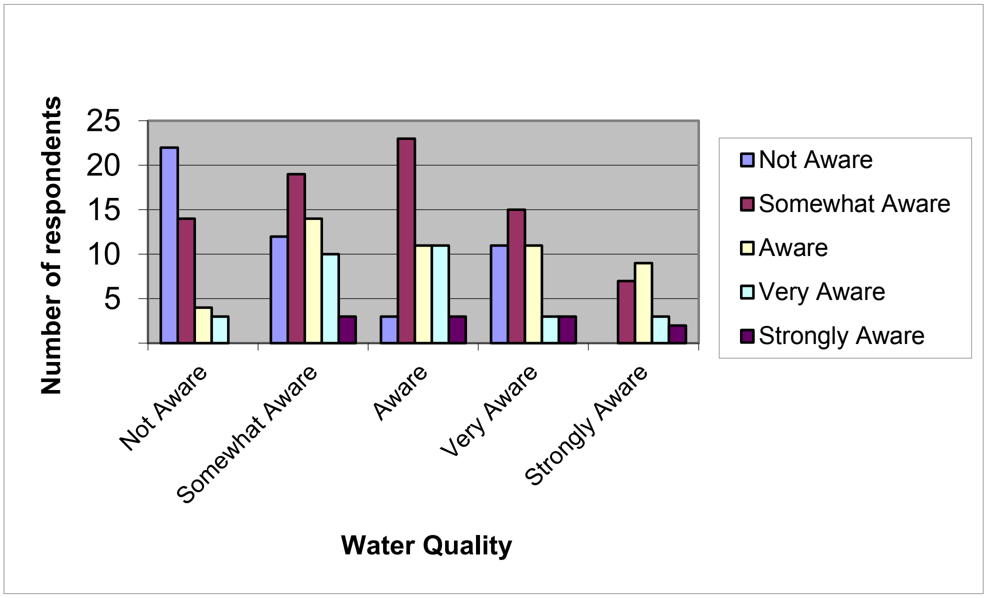



**Figure 6.15:** Crosstabulation of water mining and water quality.

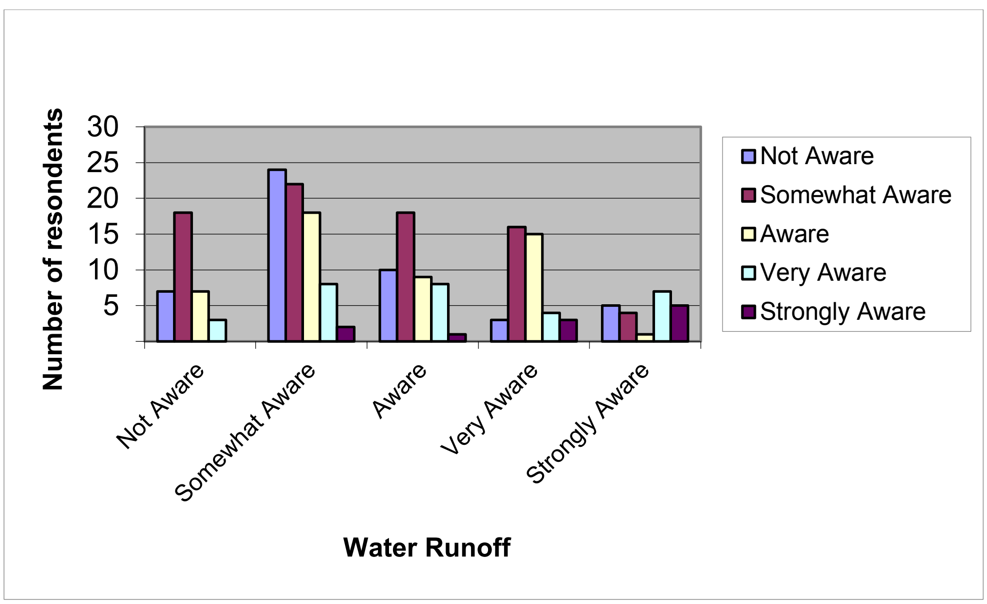



**Figure 6.16:** Crosstabulation of water mining and water runoff.

**Figure 6.17:** Reservoir pond on the Madaba Plain.

Water quality and water runoff awareness had a low correlation with r = .200 at .01 significance. A slightly better correlation was between water quality and desertification awareness with r = .260 at .01 significance. Figure 6.18 demonstrates the relationship between the variables. 22% of all respondents were not to slightly aware of both categories, whereas 17% were very to strongly aware.

Both water quality and water runoff affect soil and Ingram et al (2008) notes that perceptions of farmers and scientists differ when it comes to soil science. Farmers tend to "know-how" but not necessarily "know-why" about soils. These differences in perception tend to complicate policy discussions between the two groups. Correct policy must begin with a clear understanding of what is occurring by all parties involved.

Water quality and methods/technology awareness were slightly less correlated with r = .220 at .01 significance. Figure 6.19 shows that 25% of all respondents ranked in the not to somewhat aware categories for both variables, while 13% ranked in very to strongly aware. Water quality and land use correlated with r = .240 at .01 significance. As water quality worsens, land use can change due to a number of reasons, particularly soil salinity levels. Figure 6.20 demonstrates the relationship between the two variables. 30% of all respondents are not to somewhat aware of the variables while 9% are very to strongly aware.

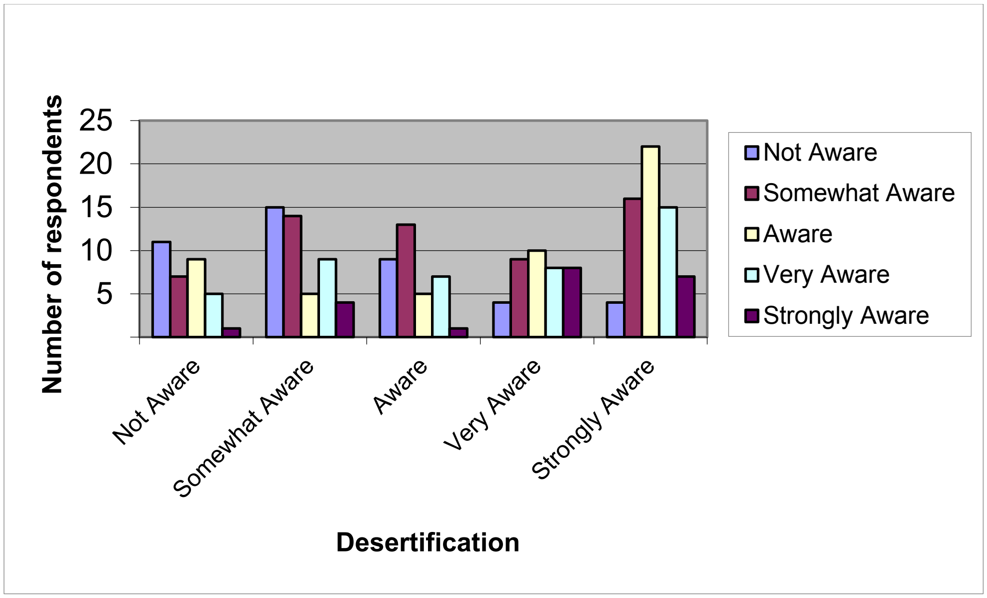



**Figure 6.18:** Crosstabulation of water quality and desertification.

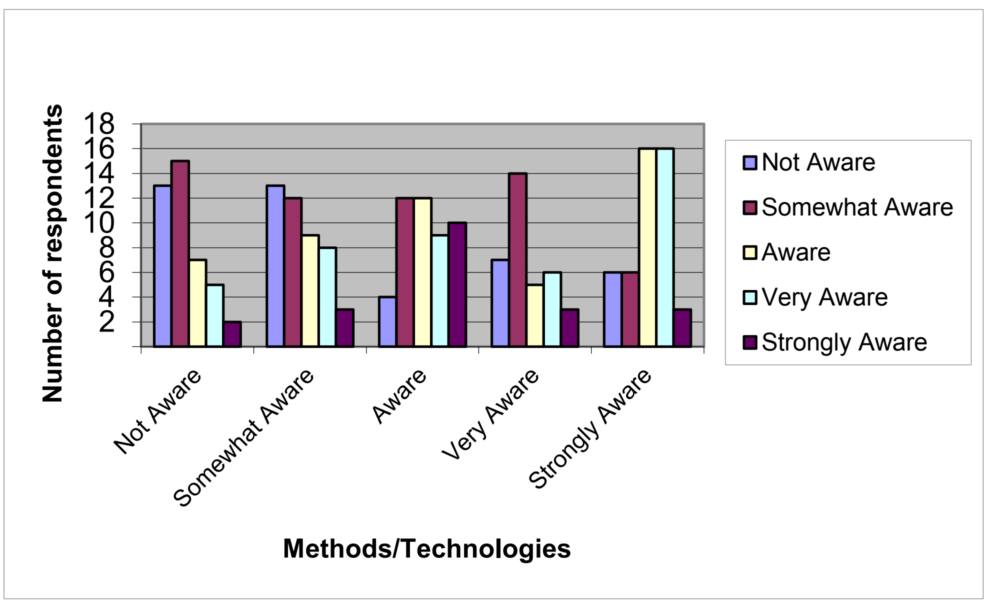



**Figure 6.19:** Crosstabulation of water quality and methods/technologies.

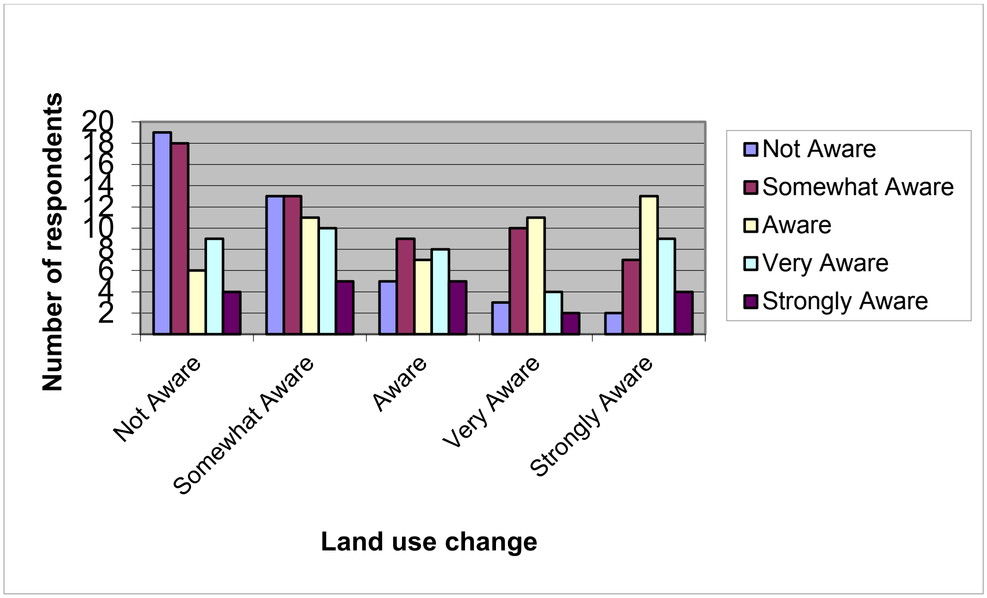



**Figure 6.20:** Crosstabulation of water quality and land use.

Desertification and methods/technology awareness had a strong correlation with r = .414 at .01 significance. This could signify that as desertification increases, newer methods and technologies are being used to combat the spread. Figure 6.21 shows the relationship of the variables. 22% of all respondents replied not to somewhat aware, while 26% were very to strongly aware. Desertification and land use change were also strongly correlated with r = .374 at .01 significance (figure 6.22). This implies that as fields went fallow due to lack of sustainability as desertification increased. 23% of respondents considered themselves to be not to somewhat aware, while 22% were very to strongly aware.

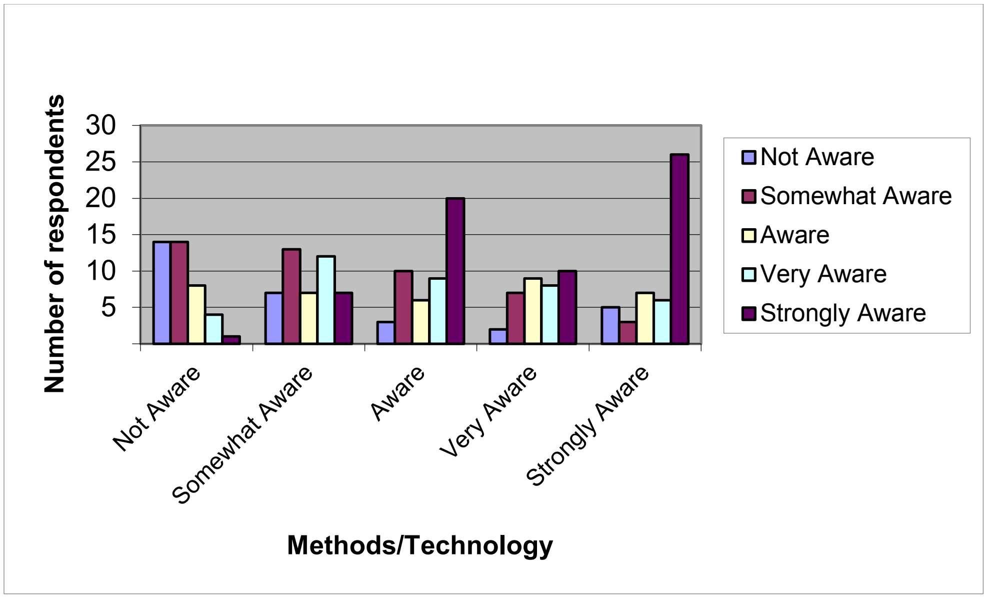



**Figure 6.21:** Crosstabulation of desertification and methods/technologies.

Prior research from Sattler and Nagel (2010) shows farmers in that study believed soil to be rated 5 on a Likert scale of 1-5. The participants of the study believed soil to be the primary resource in agricultural production and the protection of fertility is important to produce high crop yields.

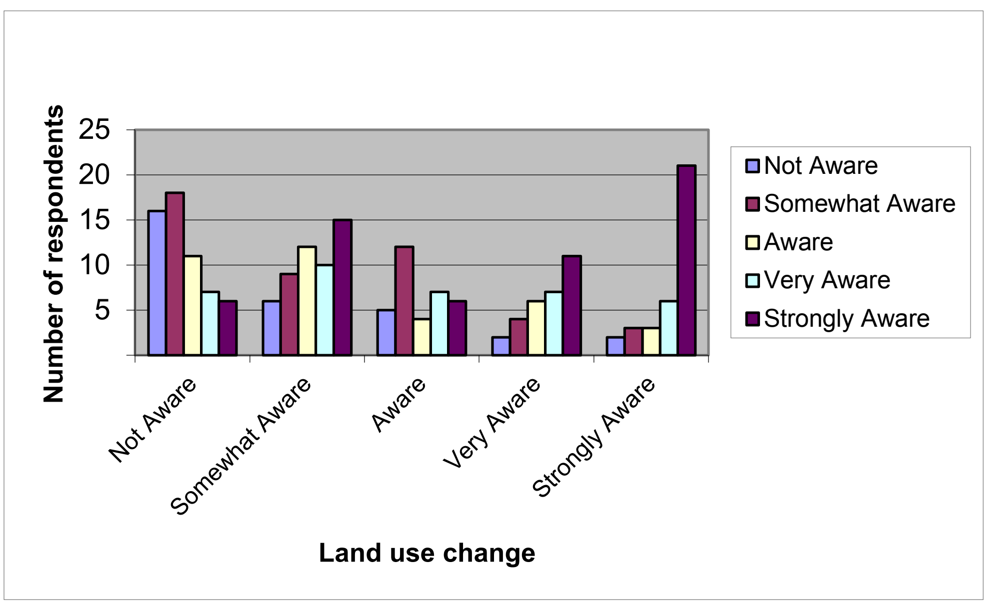



**Figure 6.22:** Crosstabulation of desertification and land use change.

Methods/tech and land use change had the highest correlation of all with r = .556 at .01 significance. In this case the $r^2$ was not calculated because the data is ordinal, but may have accounted for 30% of the variability. This is logical considering that any land use change taking place that isn"t caused by desertification is usually implemented by the use of new methods or technologies. Figure 6.23 demonstrates the relationship of desertification and land use change. Overall the percentage of those not to somewhat aware is 30% as opposed to 21%.

In the case of agriculturalists, adoptions of a new method or technology can be attributed to a number of issues, such as the characteristics of the farmer, the characteristics of the practice, and the relative advantages compared to the existing practices (Greiner et. al 2009). To further examine this point, Sattler and Nagel (2010) state:

> "A risk-averse farmer will hardly implement conservation measures that bear a high risk of failure. And, given the opportunity, a farmer who takes interest in nature protection issues might rather opt for a more environmental-friendly measure, even if the respective measure is more expensive than a farmer who is more orientated on cost-effectiveness."

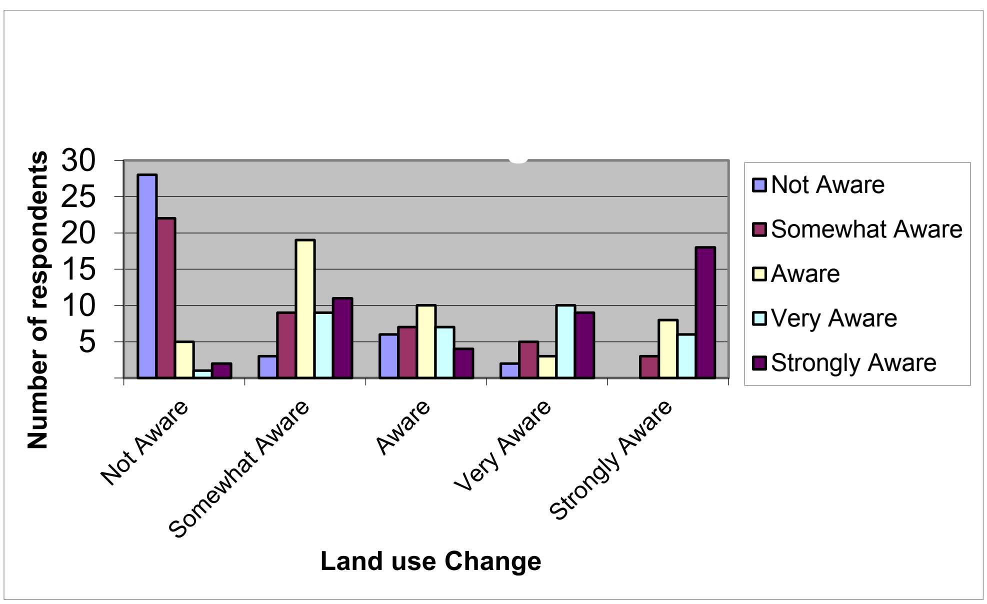



**Figure 6.23:** Crosstabulation of methods/technologies and land use

**Analysis: Land use and Water Depths**

Zonal histograms for land use were produced using the Jenks classifications to ascertain the relationship between the two for each year of the study (figures 6.24 to 6.27). Table 6.1 shows the descriptive statistics with the values being measured in pixels. As can be seen in most cases the standard deviation is quite high and in the case of 1998 actually exceeds the mean.

Closer inspection of the histograms reveals the distribution of the number of irrigated agriculture pixels. The 1991 data shows a negative skew. The ranges within the Jenks classifications for this year are low as the total depth to water range is approximately 20m.

The 1998 data was unique in that the standard deviation exceeded the value of the mean. The distribution is positively skewed, with a very low number of pixels within the lowest two Jenks zones.

The ranges within the 2002 dataset are predominantly negative. The distribution of irrigated pixels in this dataset is bimodal. There are a negligible number (14) of irrigated pixels within the only positive range. This dataset also shows the larges variance within the Jenks classifications at approximately 85m. The 2007 dataset has a positive skew to it. The majority of irrigated pixels fall within the negative ranges.

Spearman‟s rho correlations were performed on the data to determine if there was a significant relationship between irrigated agriculture area and changes in water depth. Spearman‟s rho was used because the Jenks‟‟ classifications are ranked from lowest to highest depth to water. The total number pixels of irrigated agriculture were used as an estimate of area. Only 2 of the 4 time periods showed a significant correlation (table 6.2, figures 6.24 to 6.27); 1991 had a correlation coefficient of .866 with a significance of .001 and 2007 with -.842 at a .002 significance. Since 8 of 10 zonal values for 1991 were in negative ranges the positive correlation is not unexpected. The maximum number of irrigated agriculture pixels is 27267 and fell within the -3.04 to -1.46 data range. The 2007 data had a much larger range, with half falling being negative. As irrigated agricultural areas increase, there is a corresponding drop in water depth; this is an expected and intuitive relationship.

**Table 6.1:** Descriptive statistics of the zonal data

| ***year*** | ***1991*** | ***1998*** | ***2002*** | ***2007*** |
|---|---|---|---|---|
| mean | 9146.3 | 5980.5 | 4774 | 3409.5 |
| standard deviation | 8178.87 | 6200.9 | 2599.9 | 3323.83 |
| median | 7467.5 | 4309.5 | 5519.5 | 2206 |

**Table 6.2:** Correlations of Depth to Water and Irrigated Agriculture

| | | | | ***1991*** | ***1998*** | ***2002*** | ***2007*** |
|---|---|---|---|---|---|---|---|
| Spearman's rho | Rank | Correlation Coefficient | | 0.866 | 0.103 | -0.539 | -0.842 |
| | | Sig. (2-tailed) | | 0.001 | 0.777 | 0.108 | 0.002 |
| | | N | | 10 | 10 | 10 | 10 |

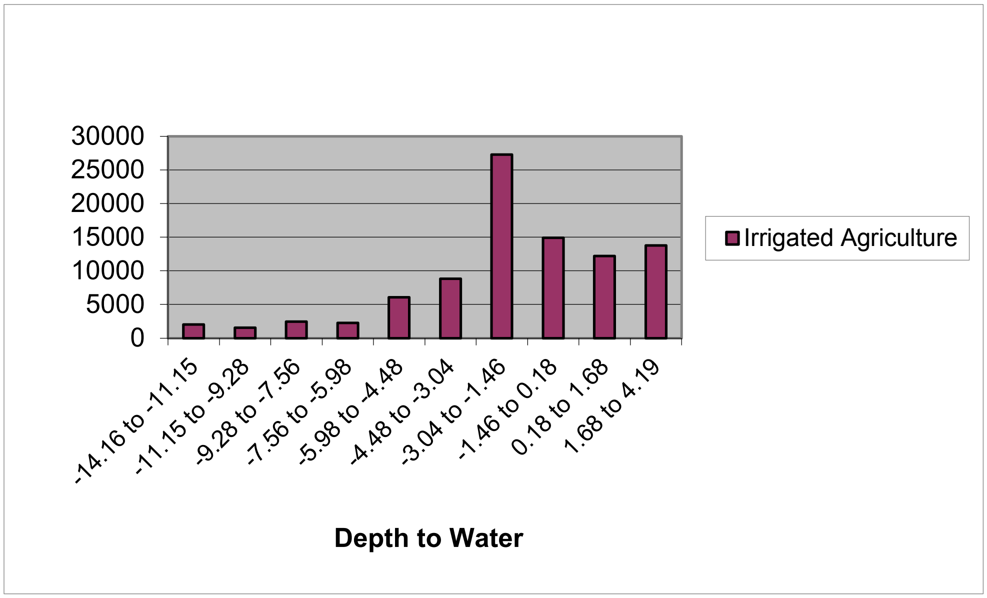



**Figure 6.24:** 1991 zonal histogram showing the number of pixels of irrigated agriculture per Jenks' water depth classification.

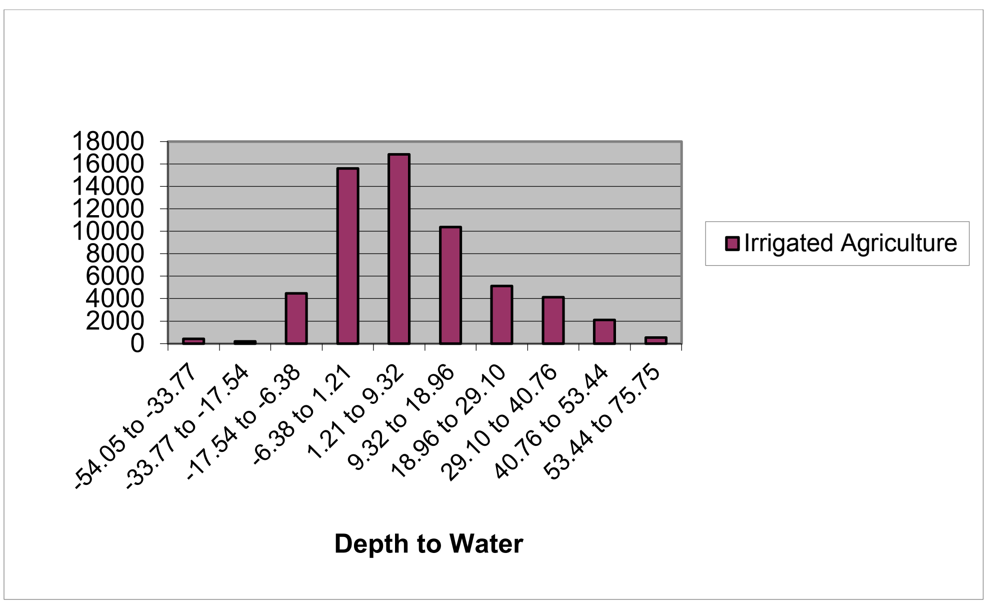



**Figure 6.25:** 1998 zonal histogram showing the number of pixels of irrigated agriculture per Jenks" water depth classification.

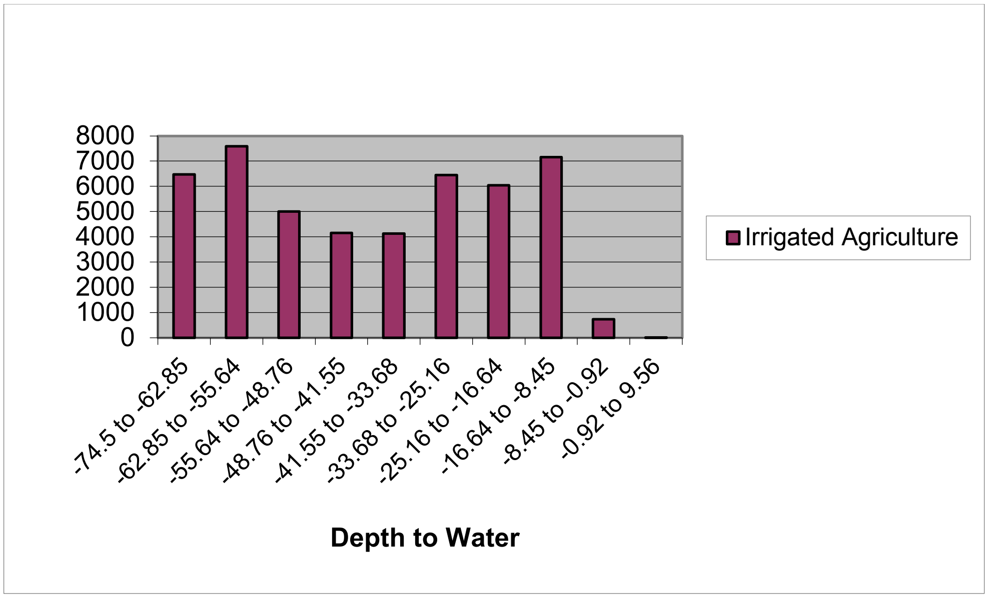



**Figure 6.26:** 2002 zonal histogram showing the number of pixels of irrigated agriculture per Jenks" water depth classification.

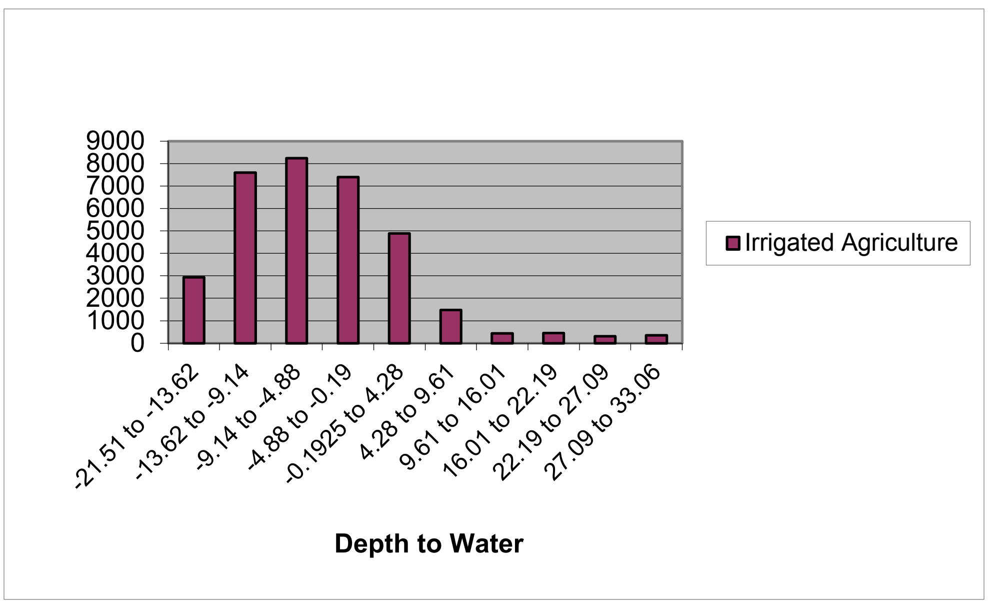



**Figure 6.27:** 2007 zonal histogram showing the number of pixels of irrigated agriculture per Jenks" water depth classification.

The continuity index for irrigated agriculture in each grid was calculated for each year of the study. As mentioned previously, this is the natural log of the sum of all irrigated area divided by the sum of all perimeter lengths in a grid cell. The grid cells were used as a reference to keep the sample areas constant. The general trend showed a decrease of continuity index values as time moved forward (figure 6.28 and appendix F). High numbered values show that irrigated agriculture areas being more continuous and lower values show more fragmented irrigated areas. Figures 6.29 to 6.32 are comparisons of the irrigated agriculture continuity index and the total percentage of irrigated areas. The data shows that the threshold for a sharp decrease in continuity occurs at approximately when irrigated area reaches approximately 4% of total grid area for 1991 and 2007. The year 1998 shows a threshold of 1%, while 2002 has a threshold of approximately 3%. Note that overall fragmentation for all time periods is low.

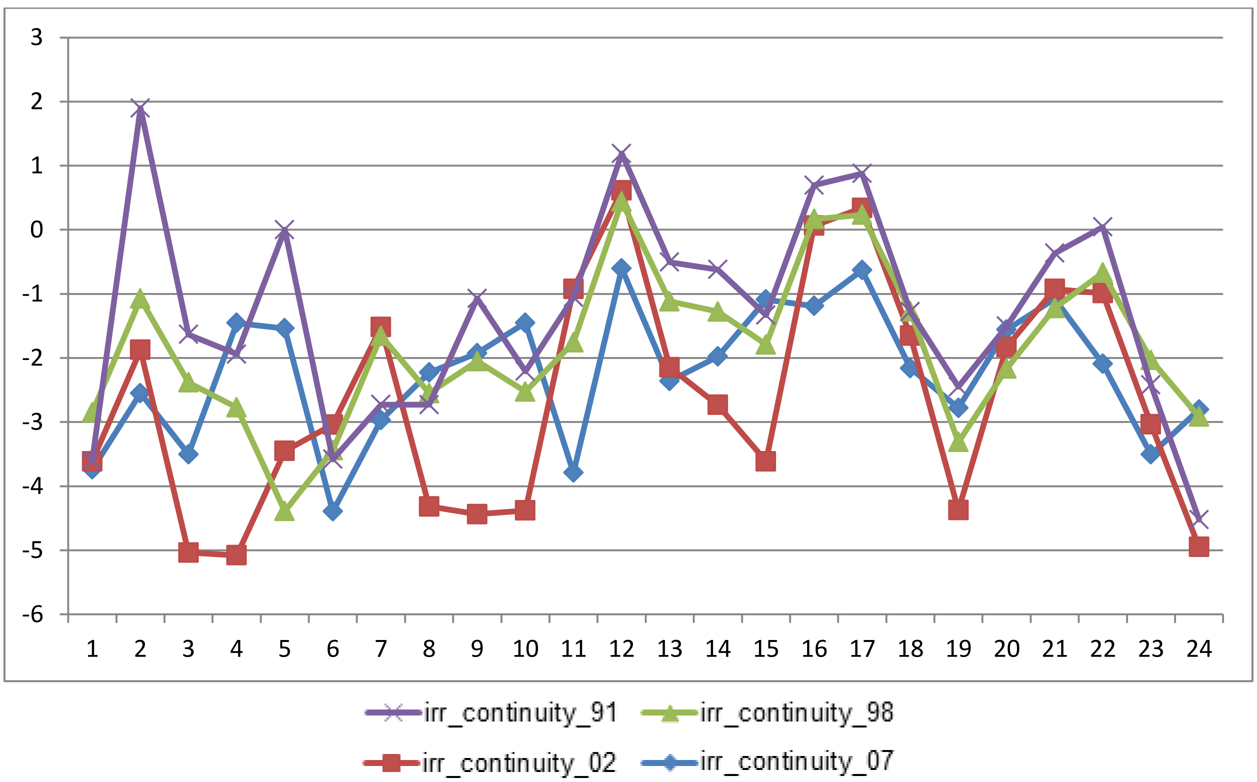



**Figure 6.28:** Continuity of Irrigated Agriculture per grid cell. The higher the continuity value, the lower the fragmentation taking place within a grid cell. Overall, continuity decreases through time.

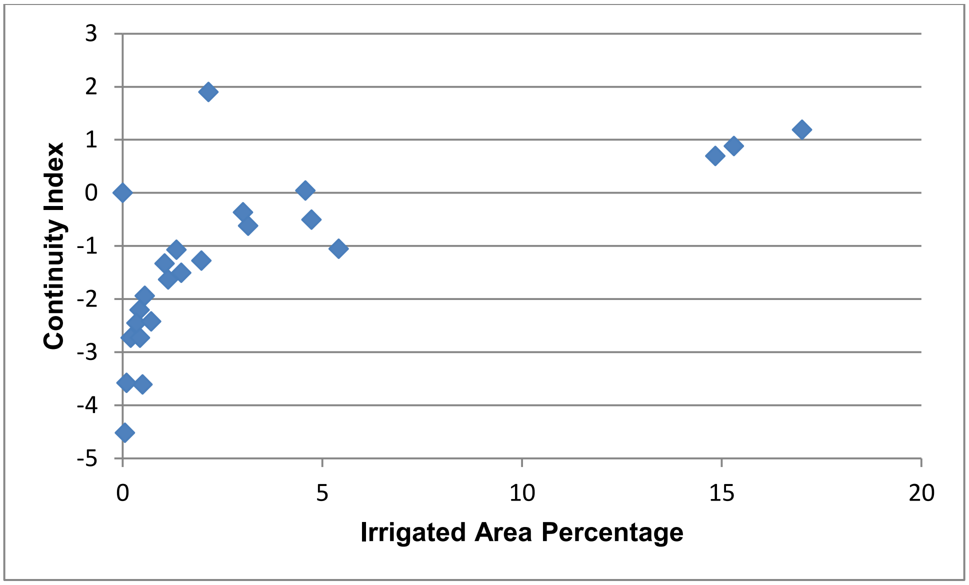



**Figure 6.29:** 1991 Irrigated Area to Continuity Index. As Irrigated percentages approach 4 percent, the continuity for grid plots sharply decreases.

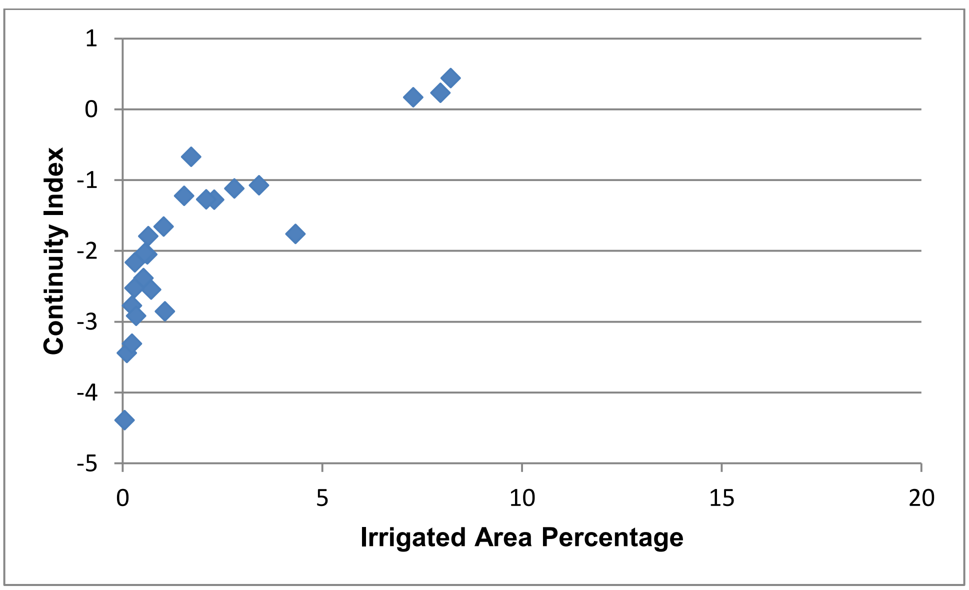



**Figure 6.30:** 1998 Irrigated Area to Continuity Index. As Irrigated percentages approach 1 percent, the continuity for grid plots sharply decreases.

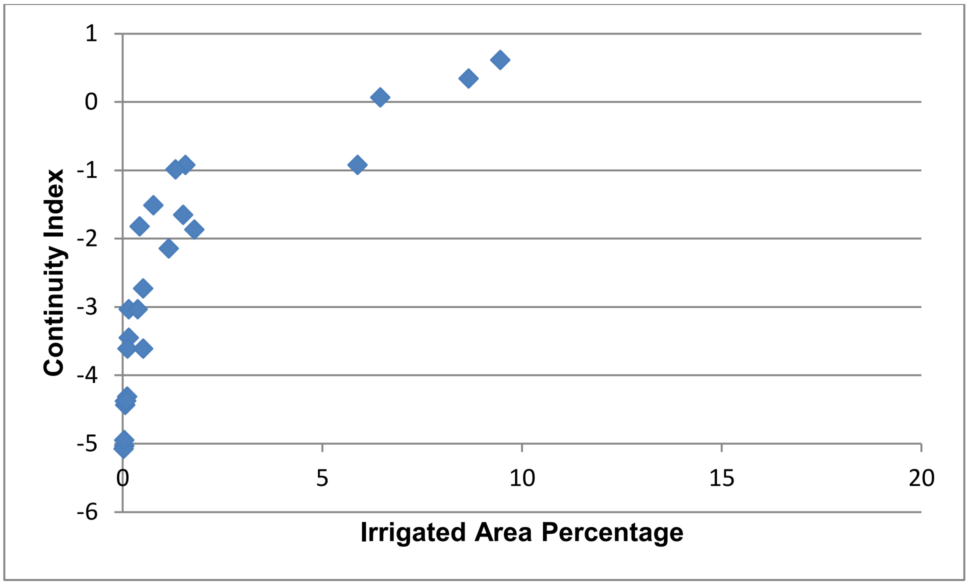



**Figure 6.31:** 2002 Irrigated Area to Continuity Index. As Irrigated percentages approach 3 percent, the continuity for grid plots sharply decreases.

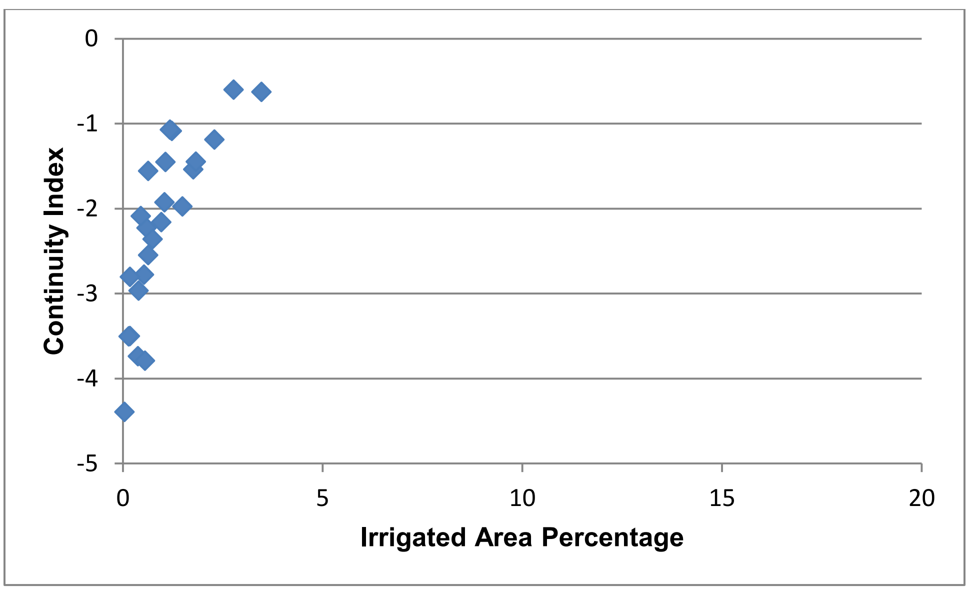



**Figure 6.32:** 2007 Irrigated Area to Continuity Index. As Irrigated percentages approach 4 percent, the continuity for grid plots sharply decreases.

Figures 6.33 to 6.36 demonstrate the comparisons of depth to water and irrigated agriculture continuity were created with trend lines to determine correlation values. In each of the case studies there was no significant correlation taking place. Trends for 1991 and 1998 were positive while 2002 was negative.  These trends are not very prominent, and have close to a 0 slope while 2007 yields a more discernable negative trend. Although the values are not significant, these trends are unanticipated.

The hypothesis put forward in this study, is that as more instances of landscape fragmentation occur, water usage becomes less efficient, and therefore more water is used per unit area. Less efficient farms are a significant issue, because as Nyariki (2011) points out, they contribute to food insecurity in developing regions. As both Fischbach (2000) and Lancaster (1999) note, fragmentation of agricultural landscape does cause less efficiency and therefore more strain on the environment. Javed et al. (2011) also support this theory as their study on small scale cotton and wheat farms showed less efficiency then their larger counterparts. Similarly, a study by Nyariki (2011) found that larger farms are 20-25% more efficient than their counterparts. Therefore, the expected results for this study was that increased fragmentation would correlate to increased water use. However, the results indicate that continuity of irrigated agriculture have no bearing on depth to water levels.

Although the landscape continuity does not affect aquifer levels, it does lead to other causes of environmental degradation such as soil erosion in the region (Shoshana 2002). A study done by Komar *et. al* (2004), has found that in deforested areas due to agricultural practices, rainfall runoff intensity has increased. He contends that the runoff increase has led to higher percentages of sediment to be eroded from the original landscape into the hydrological system. This can have two primary effects, such as stressing aquatic species that are not used to this increased sediment load as well as increased agricultural waste and pesticides. The other stress would be on any forested landscape in the Madaba Plain region, which would lose much of the nutrient rich sediment, which in turn would lead to an overall weakening of the remaining floral organisms that reside in the area.

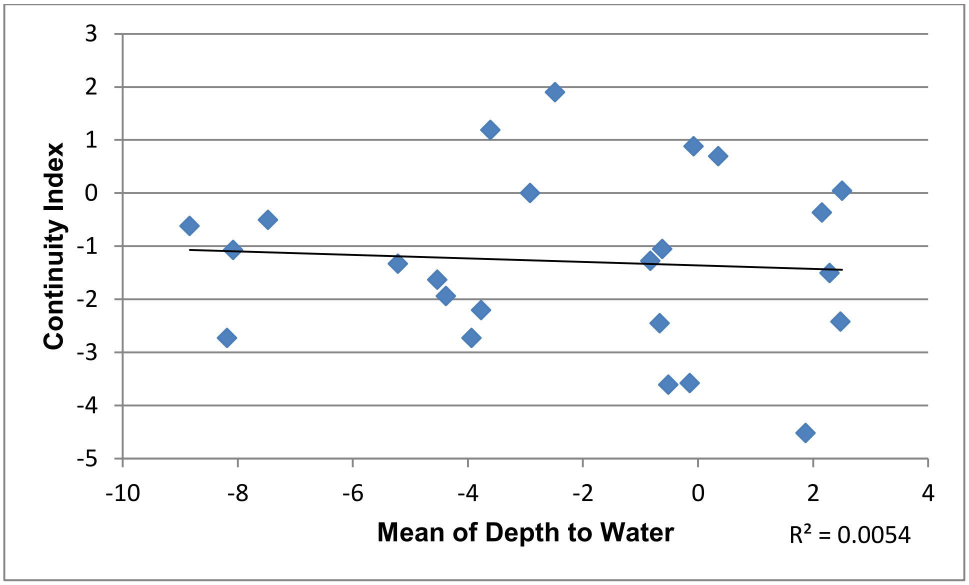



**Figure 6.33:** Depth to Water vs. Irrigated Agriculture Continuity, 1991. A Pearson"s R correlation was administered to determine if there is a significant relationship between the two factors. No significant relationship was found.

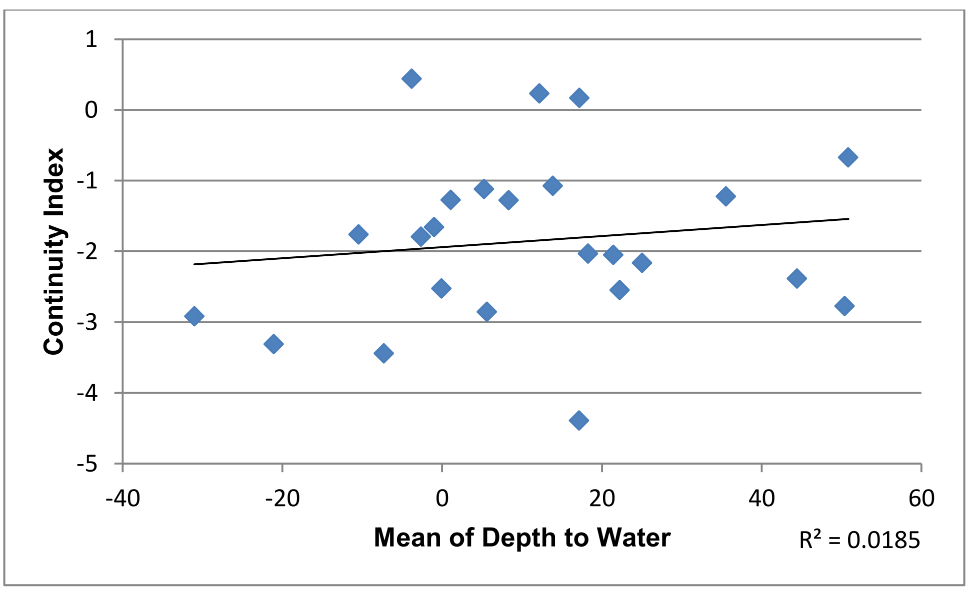



**Figure 6.34:** Depth to Water vs. Irrigated Agriculture Continuity, 1998. A Pearson"s R correlation was administered to determine if there is a significant relationship between the two factors. No significant relationship was found.

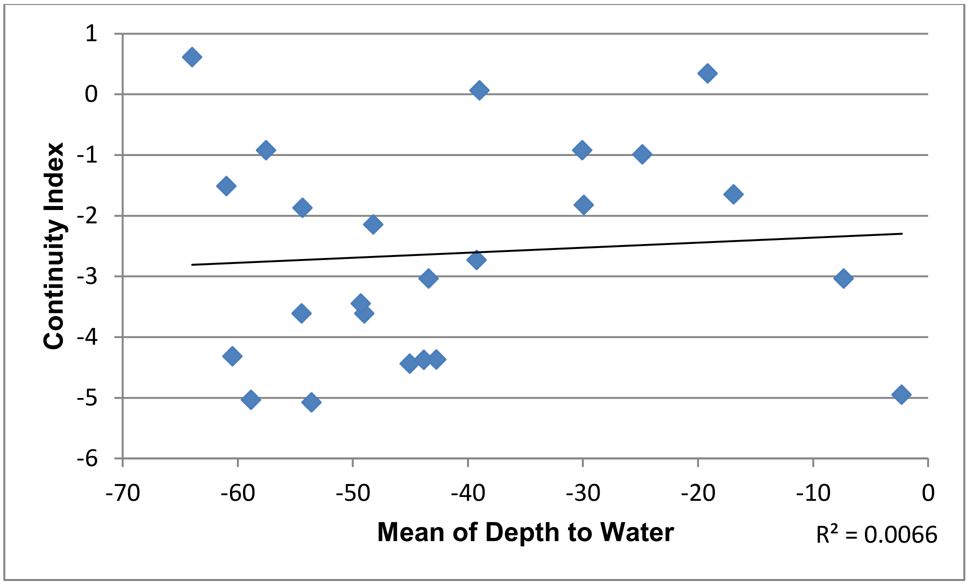



**Figure 6.35:** Depth to Water vs. Irrigated Agriculture Continuity, 2002. A Pearson‟s R correlation was administered to determine if there is a significant relationship between the two factors. No significant relationship was found.

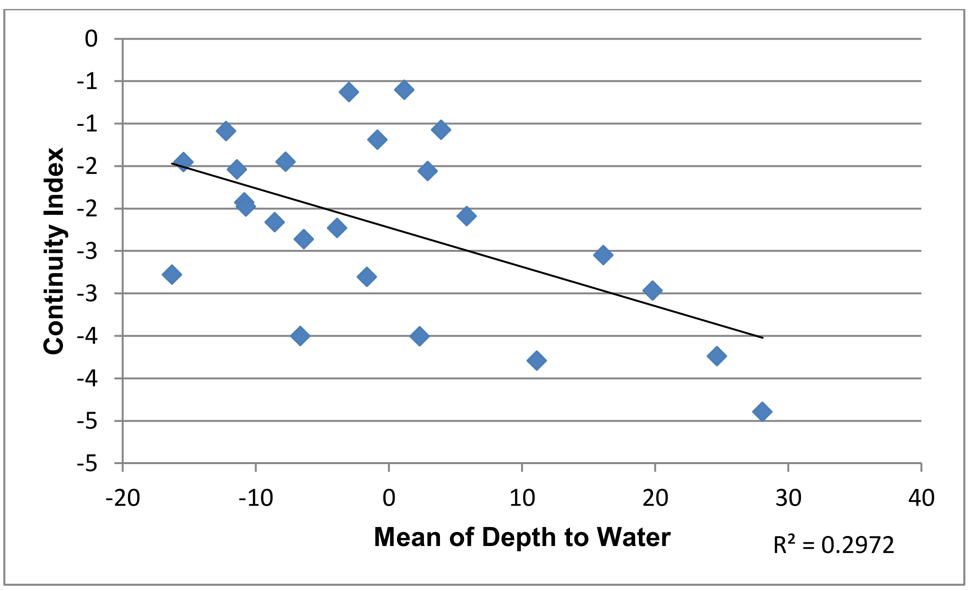



**Figure 6.36:** Depth to Water vs. Irrigated Agriculture Continuity, 2007. A Pearson‟s R correlation was administered to determine if there is a significant relationship between the two factors. No significant relationship was found. This year however did have the highest correlation of all the time periods involved in the study.

One of the most relevant effects of fragmentation is on floral and faunal organisms produced by the fragmented landscape. Kimberly and Crist (1995) define the critical threshold as the proportion of the landscape at which populations shift from random to clumped distributions. He predicts that fauna specialized for a certain habitat will tend to aggregate when their preferred habitat reaches approximately 40%. Generalized species that are mobile tend to form aggregated populations at the 35% mark.

If the critical threshold is reached, and species begin to aggregate, MacArthur and Wilson (1967) contend that genetic variation will erode through genetic drift, which will in turn promote inbreeding of a species. This in turn will lead to a less fit and less adaptable population that will be more prone to extinction. Hamrick and Aldrich(1998) gives a prime example of a genetic bottleneck that occurs due directly to fragmentation. His study deduced that 68% of trees within tropical rain forests fragmented with pasture areas were more likely to contain offspring from the pasture. This, in his estimate was due to a number of factors, such as less competition from other trees and better mobility from winds. After a generation, the pasture offspring will begin breeding with one another, causing weakness within the gene pool. Another detriment to species living in fragmented landscapes is the increase of predation that occurs. Certain species of fauna that are not native to the interior of a forest have easier access to species that may not be able to defend themselves. Batary and Baldi (2004) found that within the edges of fragmented landscapes, avian nests experienced an increase in predation due to invasiveness of a non-native predatory species.

The land use data demonstrates that continuity of irrigated landscape does not seem to contribute to aquifer deficits, so for the time being, land use regulations in this regard should remain a low priority. Monitoring activities that further break up contiguous segments should be continued in the event that land use becomes fragmented and untenable.

Although continuity does not affect aquifer levels, irrigation in general still poses a dire threat to Jordan‟s water security. The data demonstrated that there was a direct correlation between the amount of irrigated agriculture and water depletion in 2 of the 4 time periods studied. To further compound issues of irrigation, approximately half of the survey respondents would change crop types as seasonal change occurred (Table 6.3). This change may cause the need for further irrigation in some cases, where water intensive vegetation is grown.

**Table 6.3:** Seasonal Crop Change

| | | ***Frequency*** | ***Percent*** | ***Valid Percent*** | ***Cumulative Percent*** |
|---|---|---|---|---|---|
| Valid | Does not Change | 106 | 47.3 | 49.3 | 49.3 |
| | Crop changes later in growing season | 109 | 48.7 | 50.7 | 100.0 |
| | Total | 215 | 96.0 | 100.0 | |
| Missing | No Response | 9 | 4.0 | | |
| Total | | 224 | 100.0 | | |

With a rising population and expanding industry, groundwater in Jordan is at a premium. Add to this is that the projected rate of urbanization at 3.1% annually, which makes groundwater in the Madaba plains area even more valuable (CIA 2009). Historically, irrigation was the sole responsibility of private landholders (Haddadan 2006). With the implementation of laws and guidelines, responsibility of irrigation infrastructure has been shifted to the Jordanian government, who deliver water to the landholders boundary. The implementation of the delivered water is the responsibility of the individual tenant. In this way, water usage can be measured by officials and revenue can be generated accordingly.

Many of the farms visited have already implemented the use drip irrigation methods (figure 6.37). This method is more efficient than traditional irrigation in that it allows for water on demand and less evaporation. Watering usually takes place in the evening to prevent excessive evaporation. The use of open air reservoirs is a counter to this as the water should be used immediately after pumping or stored in a more efficient manner.

**Figure 6.37:** Example of drip irrigation technology on a Jordan vegetable farm near Maʿīn.

**Figure 6.38:** Open air reservoir with a pumping station near Madaba.

Many of the open air reservoirs were constructed in the manner of figure 6.38. The large exposed surface area is conducive to evaporation in arid and semi-arid regions like the Madaba Plain. Shiklomanow (1999) points out that more water is lost through reservoir evaporation then through human consumption. Note the use of an elastic plastic tarp as a lining, as opposed to a more permanent structure (figure 6.38). Although this was done to reduce costs of construction, any tears in this tarp may increase water costs due to loss. Furthermore, the volume of water being pumped to replenish evaporation losses is significant.

The depth to water data from this study demonstrates significant increases in water levels in the Amman municipal area throughout the time period of the study. This is attributed mostly to leakage of the pipeline infrastructure with an estimated 50% of Amman‟s water supply (www.water-technology.net/projects/greater_amman) being lost, as wastewater is not returned through the sewers. This water should be captured and reprocessed as it can help alleviate agricultural needs.

Treated wastewater is already used as an ancillary source of irrigated water. Haddadin (2006) states that 81 MCM of wastewater was reclaimed in 2002, and the Ministry of Water and Irrigation (2002) estimates that the amount of wastewater produced will reach 200 MCM by 2020 and have plans to allocate the majority to agricultural purposes. Overall, 13.7% of all water used for agricultural purposes in Jordan came from treated wastewater. Reclaiming lost water and using it towards irrigation as treated wastewater is paramount to any water conservation strategy that is implemented. Investments in modernizing and maintaining infrastructure should be a high priority of the Jordanian government, as it will allow some relief to water shortages.

Haddadin (2006) points out that although there are benefits to reusing wastewater, there are also disadvantages. As has been noted, treated wastewater supplements existing water resources. Another benefit for using treated wastewater is the natural fertilizer present that helps augment crop growth. Disadvantages include higher salinity content that causes further soil degradation and the possible rise of disease from pathogens from water that may have not been treated correctly (Katzenelson 1976).

Although the use of treated wastewater has an overall benefit in regards to water consumption, it has several adverse effects on farmers using it (Haddadin 2006). As of 2006, the price of treated wastewater is the same as the price of freshwater. Along with this issue, farmers were subjected to greater cost to safeguard against biohazards that may be present in any affluent. Also, in some cases, the alkalinity of the wastewater neutralized fertilizers employed by the farmers. This in turn led some farmers to spend more money on potable freshwater then they would have if they received their freshwater quotas (Haddadin 2006). To add to this, studies done by both Hijawi (2003) and Majdalawi (2003) have shown a decrease in crop yields when using treated wastewater.

Further inspection of location is warranted to see if this factors into people‟s perception of risk. Previous studies such as Cutter and Borden (2009) have looked at risk of mortality due to natural hazards. A crosstabulation (Appendix C) of location and the Likert scale questions was produced to examine the locales of Amman, Madaba, Ma‟in and Um al-Basateen. In the Location vs. overpumping of aquifers category, only 6% of Amman respondents were very to strongly aware, compared to 11% of Madaba respondents. Um al-Basateen respondents scored at 10% Strong to Very Aware, while Ma‟in respondents followed at 7%. Figure 6.39 further examines the spatial variance of awareness levels. Although Ma‟in scored relatively low in the very to strongly category, the town also had the lowest not aware score. Amman and the region of Um al-Basateen both had very high percentages of not aware in this category at over 50%.

Location vs. water mining showed a doubling of awareness levels at 9% for Amman respondents to 18% for Madaba respondents (figure 6.40). In Um-al Basateen, respondents had a similar score to Amman at 11%. No respondents in Ma‟in answered strongly aware to this phenomenon, however, over 30% answered very aware. This indicates that respondents Ma‟in have a general understanding of the mechanisms involved in water mining. More telling, 71% Amman respondents answered not to somewhat aware on this issue.

For location vs. water quality, respondents scored 23% to 35% Amman to Madaba respectively (figure 6.41). Similar low scores were present for Um al-Basateen at 30% and Ma‟in at 23%. Amman again scored the lowest at approximately 60% of respondents answering somewhat to not aware. 45% of Ma‟in residents also scored low.

Location vs. water runoff was the closest category (figure 6.42), with respondents from Madaba having a higher level of awareness at 27% to 26% then respondents from Amman. Um al-Basateen had the highest percentage of awareness, with 40% responding very to strongly aware. Ma‟in had the highest rate of somewhat to not aware at over 60% followed by Madaba at 49%.

The category of location vs. desertification (figure 6.43) contained the largest single strongly aware percentage of the study. In this case, 61% of Ma‟in respondents answered strongly aware, and another 19% answered very aware for a total of 80. Madaba respondents answered 51% very aware or better while Amman respondents awareness was 36%. 34% of Um al-Basateen respondents answered very to strongly aware, while 50% answered somewhat to not aware.

In the category of location vs. methods/technologies (figure 6.44), Ma‟in again had a very high score of 69% in the very to strongly aware. Amman scored 32% to Madaba‟s 49%. Um al-Basateen again scored lower than the other towns with only 15% of very to strongly aware.

Finally, location vs. land use (figure 6.45) also had Ma‟in with a large percentage of very to strongly aware at 65%. Madaba respondents scored 29% to Amman respondents 16% for this category. Both Amman and Um al-Basateen had high percentages of somewhat to not aware at 64% and 49% respectively.

Fisher‟s Exact Tests were completed for each of the pairings; however none of the categories returned statistically significant results. This may be a result of sample size for each location. There have been attempts to map risks of hazards in order to understand and create policy (Boggett et al. 2000, Cruden and Fell 1997). Generally speaking, awareness of the various risks was higher in the southern area of the study site and became lower heading north. This is an interesting phenomenon and may be due to a number of factors.

One reason for the discrepancies from north to south could be due to Amman being the capital and commercial center of Jordan. Socio-economic influences such as employment type may factor into lack of awareness. Another factor is that water in Amman is readily available and delivered by the municipality. Furthermore, respondents from Um al-Basateen are in close proximity to Amman and may work there. Both Madaba and Ma"in are smaller than Amman, and are more reliant on agriculture for sustenance and economic livelihood.

The pattern of awareness seems to inversely follow of the amount of precipitation on the Madaba Plain. Oliver-Smith (1996) notes that a natural disaster such as drought is a totalizing event that affects all aspects of community life. Although the entire region is considered semi-arid, the distribution of precipitation decreases from north to south. Therefore, drought like conditions have a higher probability of occurring around the southern population centers. As mentioned previously, these dry conditions in conjunction with an extreme weather event can cause extreme soil degradation (Schmidt et al. 2006). This may explain why desertification scored so highly in Madaba and Ma"in. Lack of precipitation is also a cause for lack of aquifer recharge, which leads to water mining, which also had an extremely high awareness score in the southern population centers.

**Summary of Findings**

Familiarity with scarce water resources may have caused the low scores for awareness on all topics. As a population lives in constant risk of a phenomenon, they may become desensitized to that phenomenon. Awareness in 6 of the 7 water issues from the survey had a mean of below 3, with the only issue over three being that of desertification. This may imply that respondents could see this phenomena manifest itself physically. However, desertification in of itself is not a water only issue, but also a climate change issue. Both overpumping of aquifers and water mining scored the lowest. Most people comprehend where the majority of their water originates, but have little knowledge of the risks associated with the water source. Knowledge of these two issues may help with conservation efforts if the respondents understood that water mining was taking place and was destroying the storage capability of the aquifers. With a vast majority of water coming from ground water sources, a need to know about these issues is imperative for conservation efforts.

A number of significant correlations were found within different categories. Education correlated highly with the income demographic as well as a number of the Likert scale questions, such as water runoff. A notable result was the relatively high correlation of age and methods and technologies. This is notable due to it being the opposite result of a similar culture dealing with a different hazard. The methods and technologies category had the highest correlations in the study with both desertification and landuse change, which may signify that new technologies are being used to improve land use that may have been impaired by desertification.

Depth to water measurements varied throughout the study area. The greatest depth decrease took place in the desert area, while the largest increase happened in the Amman area, and is attributed to poor maintenance of infrastructure. Irrigated landuse significantly correlated in 2 of the 4 time periods studied, while another year showed a high correlation that was not deemed significant (table 6.2). Overall continuity was generally low, and continuity of irrigated plots decreased through time (figure 6.28, Appendix G). When examining Likert responses in regards to location, awareness levels tended to be more aware for population centers to the south.

This may be attributed to precipitation levels and/or socio-economic factors such as type of employment.

Awareness levels varied throughout the population centers in the study area. Awareness for overpumping of aquifers was generally low, with slight increases in Madaba and Maʿʿin. Awareness of water mining fared slightly better overall, and although respondents in Maʿʿin did not respond strongly aware, a very high percentage responded very aware. Water quality awareness fared better in the Um al-Basateen and Madaba areas as opposed to Amman and Maʿʿīn, while awareness for water runoff fared better in the north as opposed to the south. Awareness of desertification, methods and technologies and landuse was very high, particularly in Maʿʿīn. The geographic distribution of these awareness levels reflects an inverse of precipitation levels throughout the Madaba Plain.

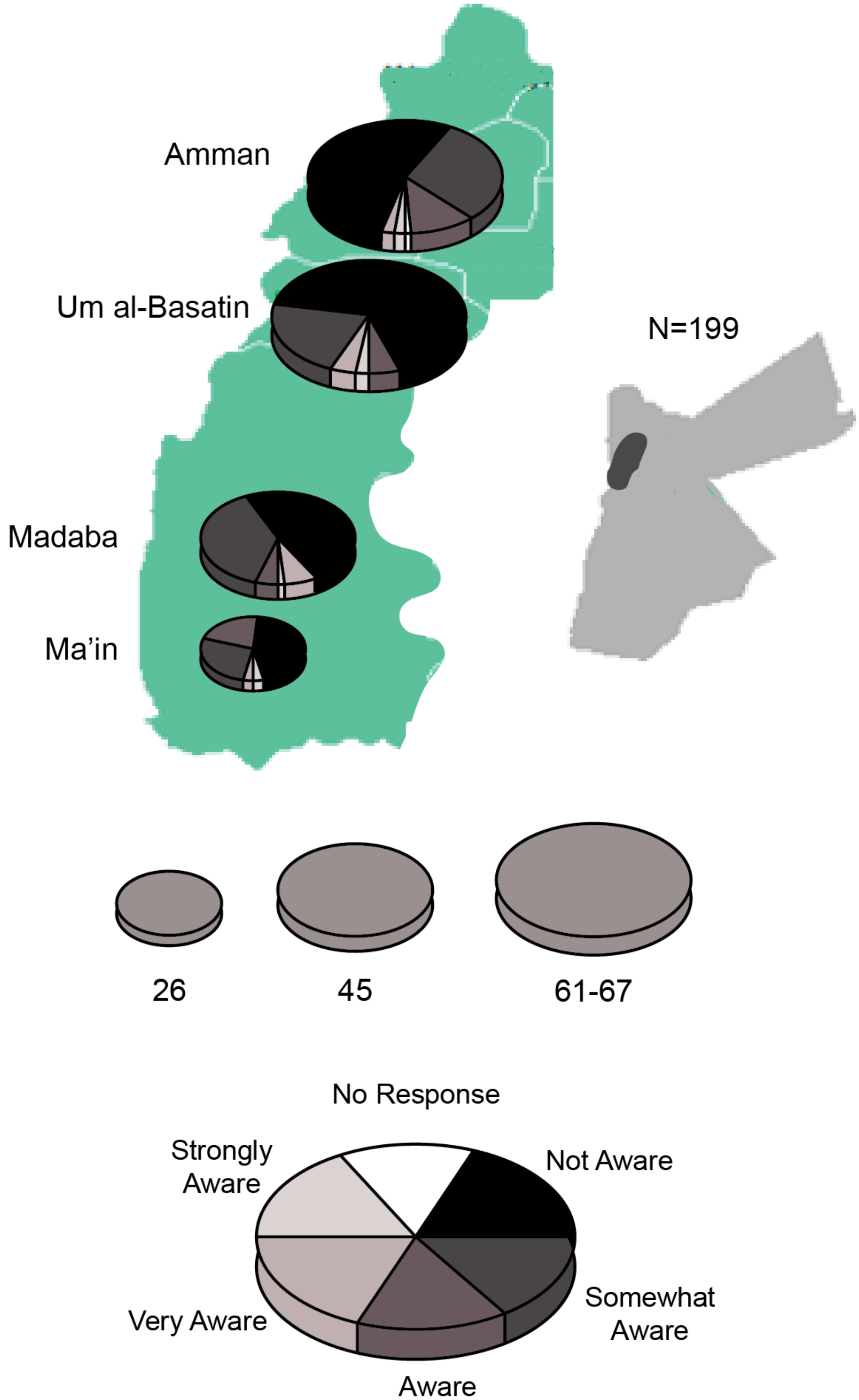



**Figure 6.39:** Perceptions of awareness for overpumping aquifers locations in the study area.

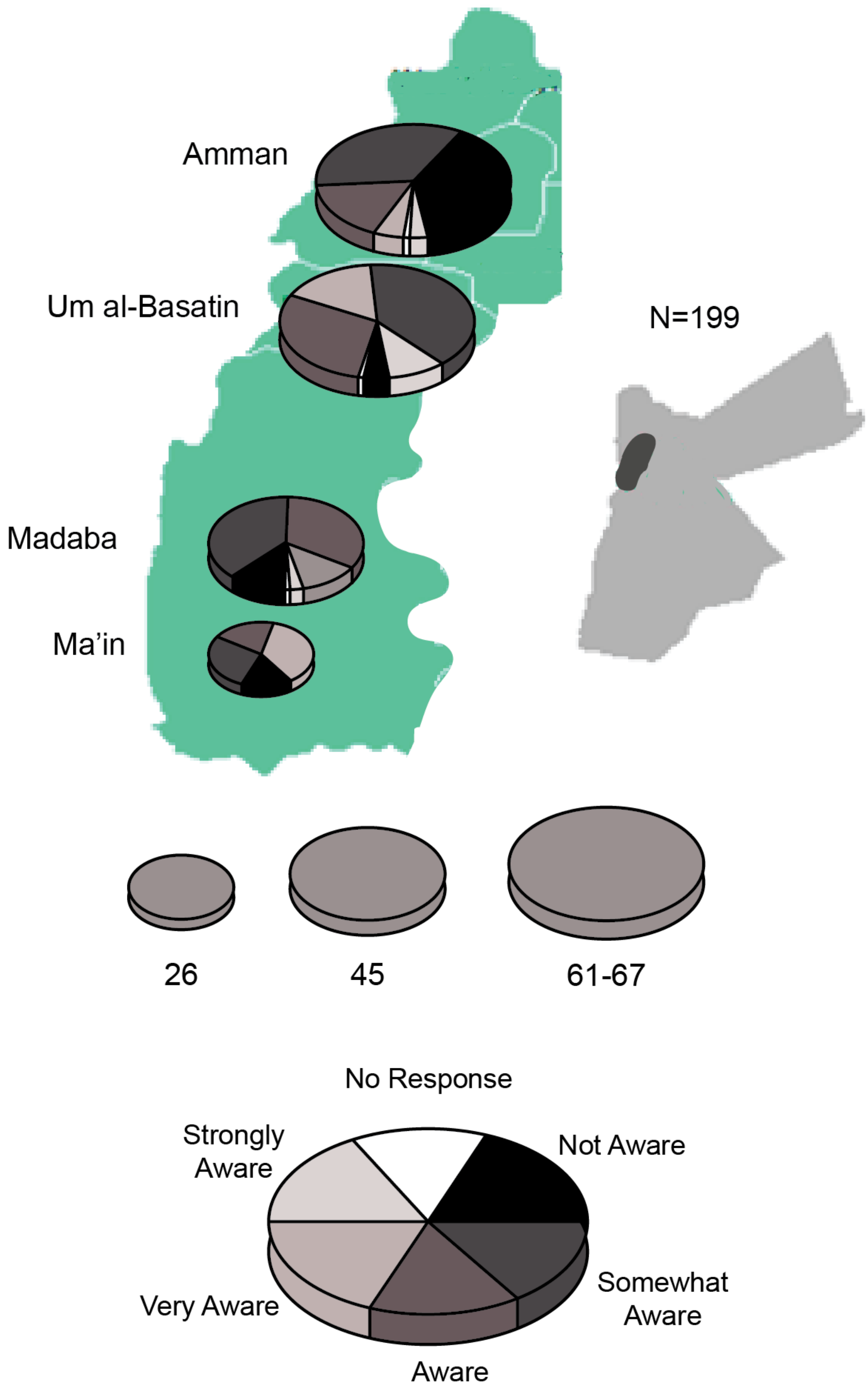



**Figure 6.40:** Perceptions of awareness for water mining for locations in the study area.

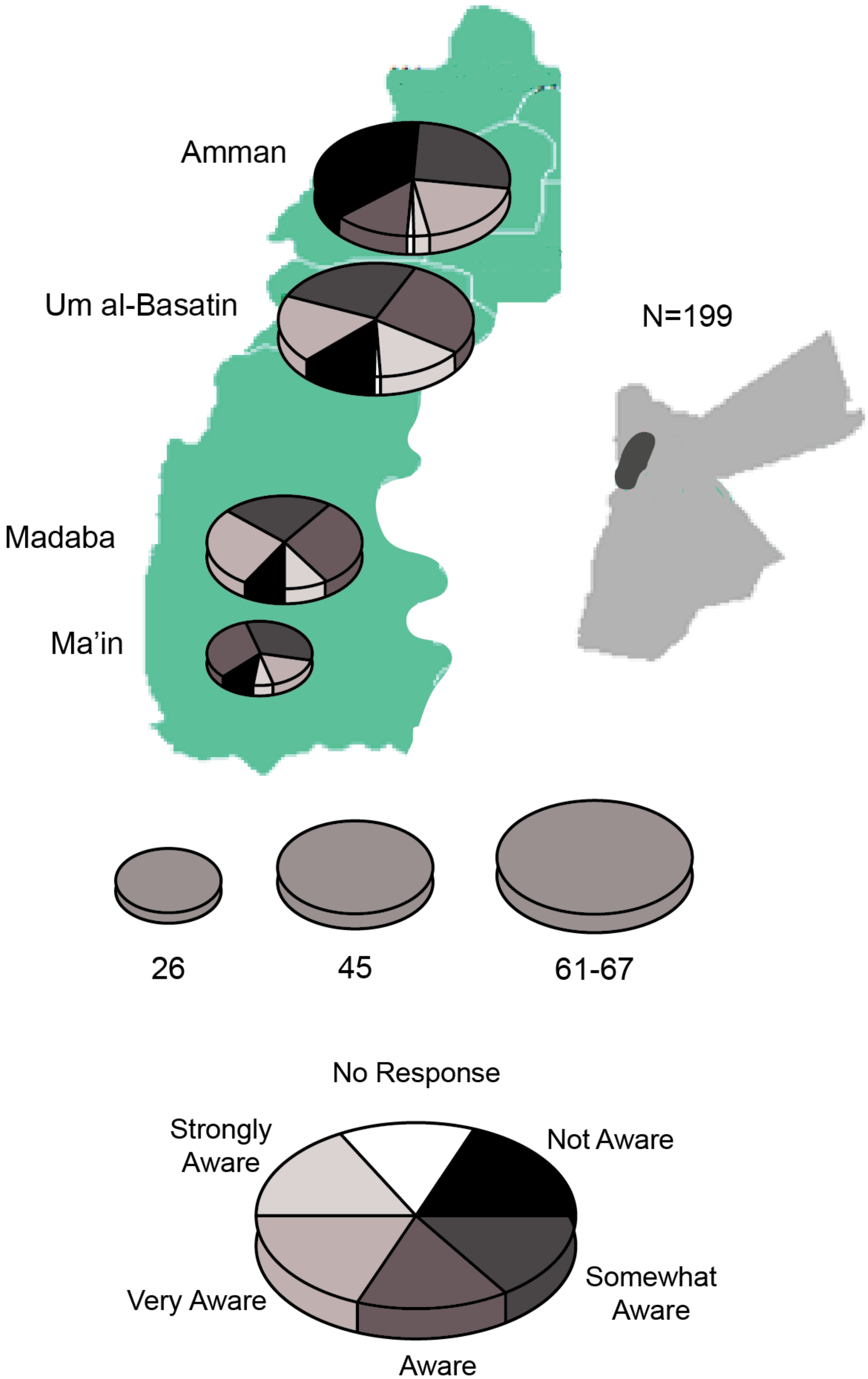



**Figure 6.41:** Perceptions of awareness for water quality for locations in the study area.

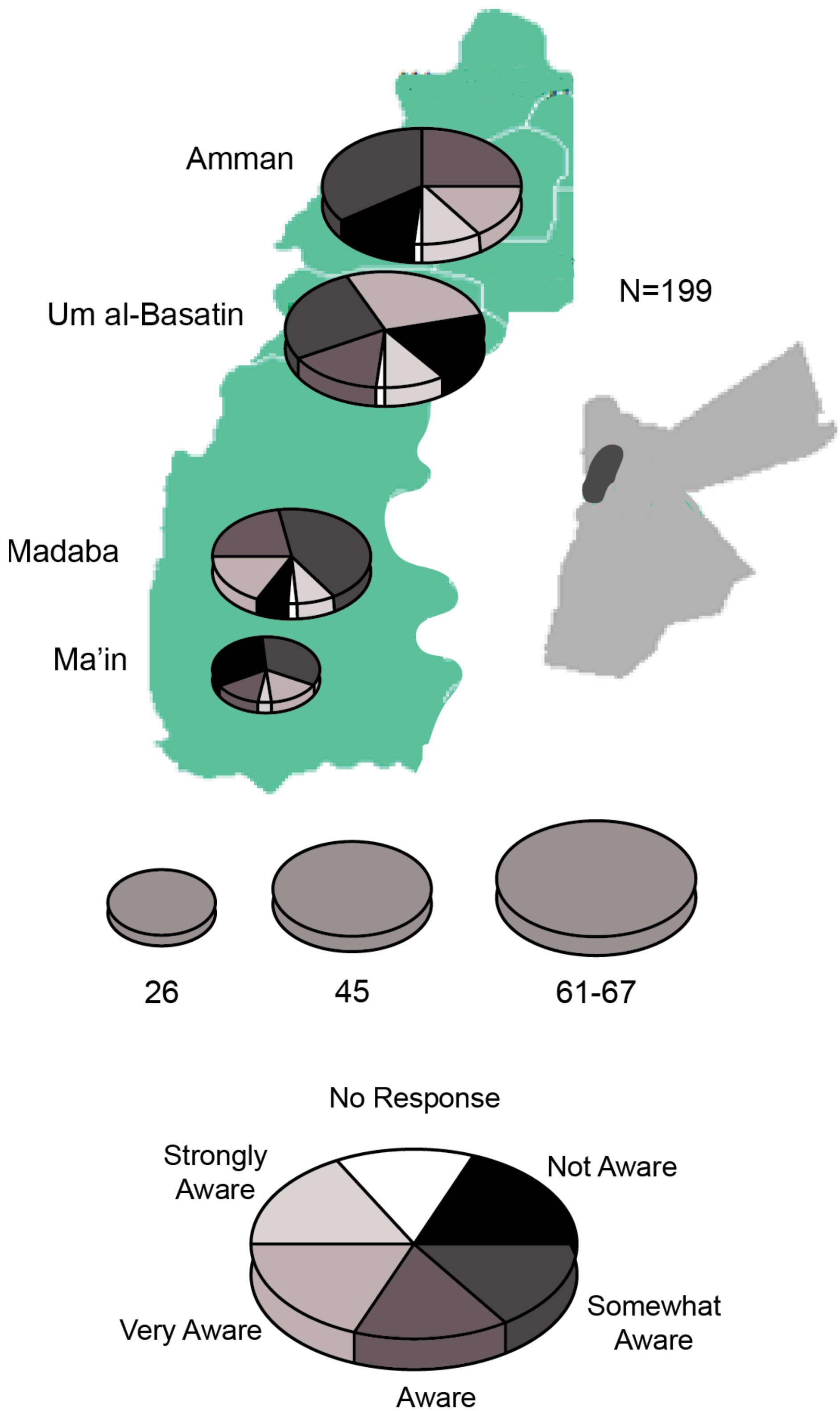



**Figure 6.42:** Perceptions of awareness for water runoff for locations in the study area.

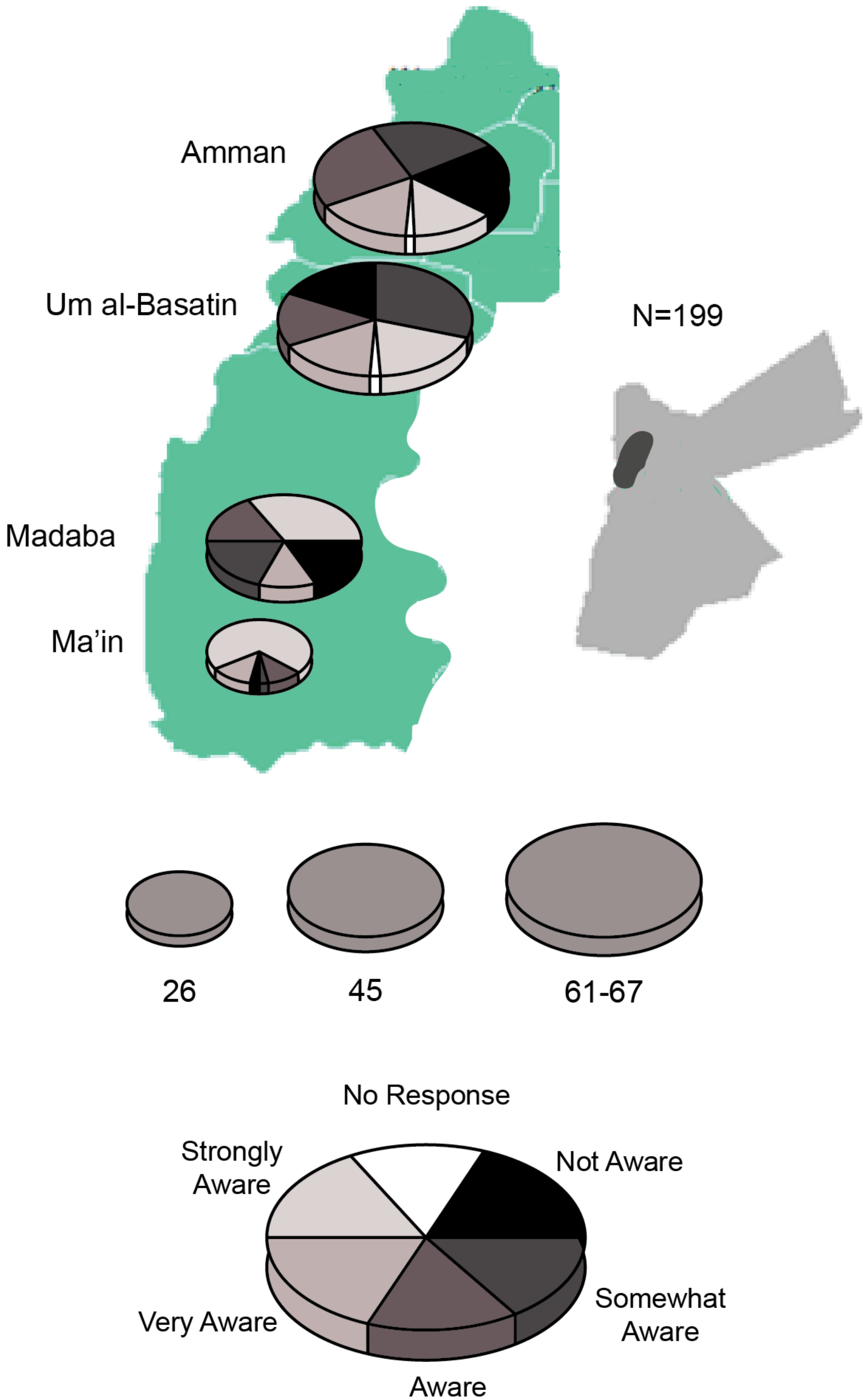



**Figure 6.43:** Perceptions of awareness for desertification for locations in the study area.

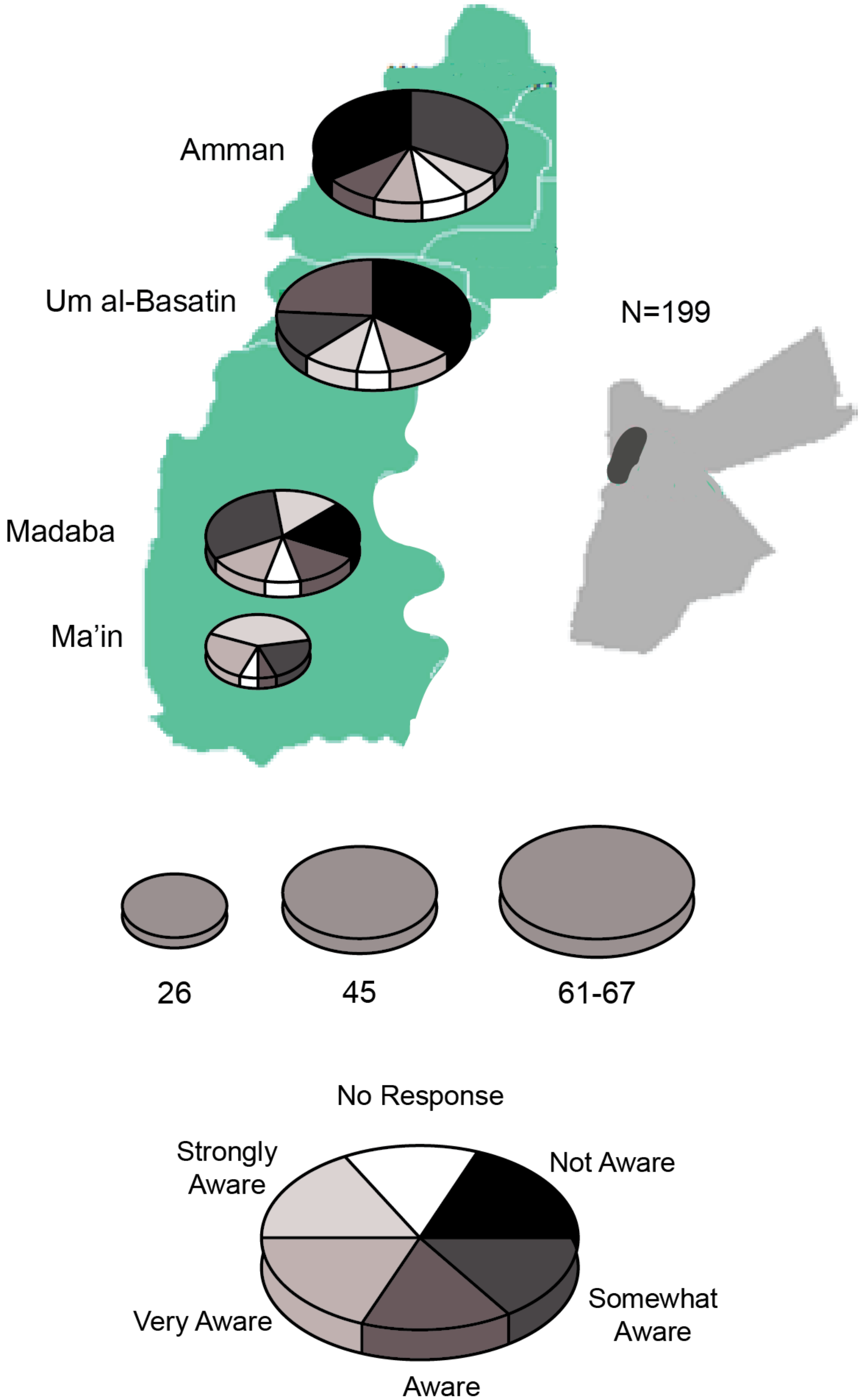



**Figure 6.44:** Perceptions of awareness for landuse for locations in the study area.

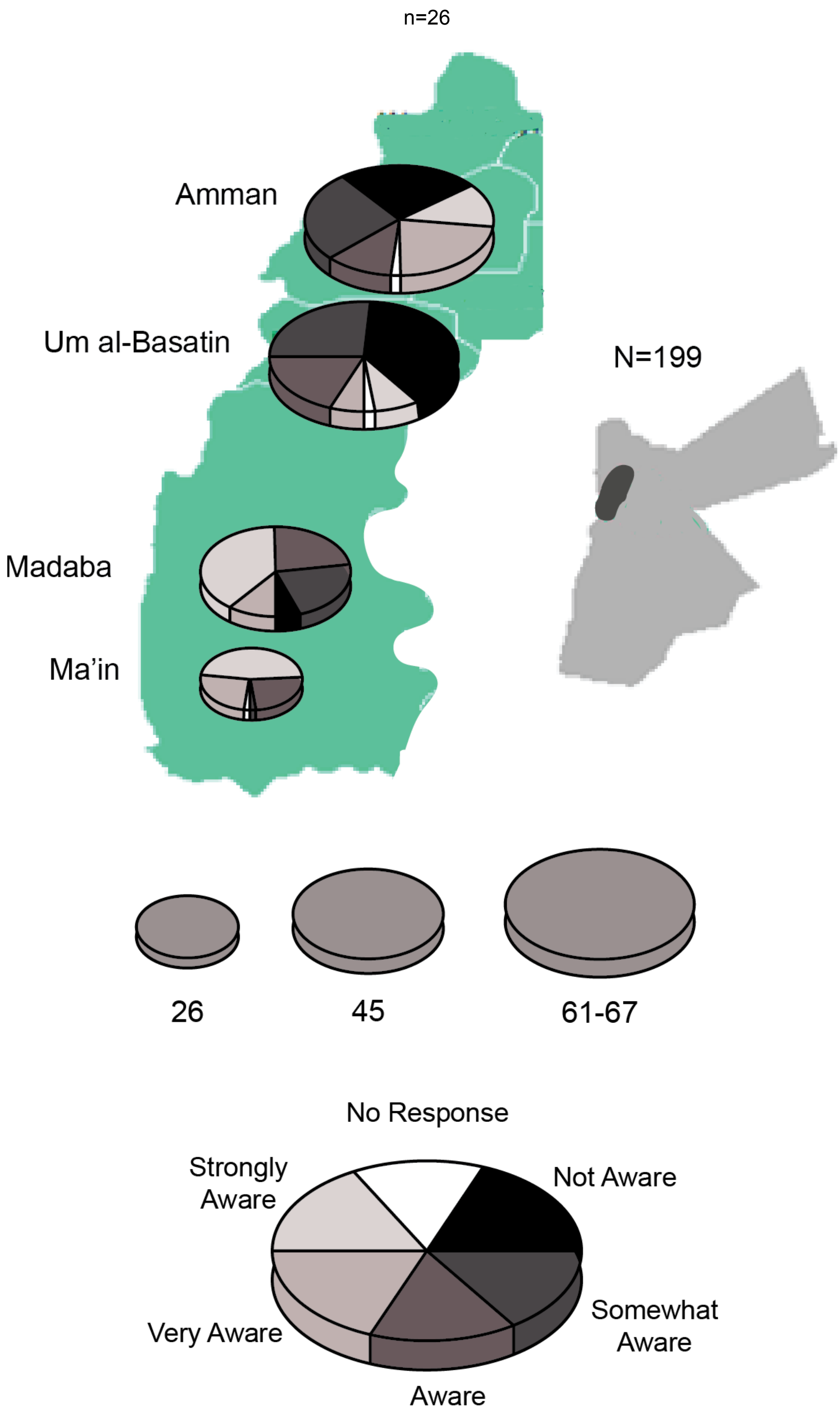



**Figure 6.45:** Perceptions of awareness for methods and technologies for locations in the study area.

# Chapter 7: Conclusion

The high demand for water for agricultural use has led to a number of environmental hazards on the Madaba Plain of Jordan. Water mining, erosion of arable soil and desertification have all increased in conjunction with changes in climate. Overpumping of aquifers is occurring at over a rate of 135-225% (Dal Santo and El Naser 2001) for the groundwater basins in Jordan. This coupled with current drought-like conditions have put an enormous strain on aquifer levels.

The country of Jordan provides an exceptional opportunity as a study as it is one of the more stable countries in the region. This is an important aspect for population growth as refugees from other countries in the region move to Jordan to flee political strife. The Madaba Plain was chosen specifically for this study due to a number of factors. This region produces the second highest quantity of wheat for the country. The region also produces a number of fruits and vegetables that are dependent on irrigation (ie. tomatoes, apples, plums). The proximity to a number of population centers provide a workforce for the agricultural industry.

Data for this study was acquired by employing a number of methods in an innovative integration. Demographic and Likert Scale data was obtained by distributing written surveys that participants completed and hand-returned. Remotely sensed data were obtained from the USGS through the glovis.gov website for the years of 1991, 1998, 2002, and 2006. Finally, groundwater data were obtained from the Ministry of Water and Irrigation in Amman.

The results of the study showed some surprising and unanticipated trends. Generally, the Likert scale answers had a low mean, and showed that respondents did not have much awareness about any of the hazards regarding water, resource use and conservation. The study also showed that education correlated with a number of responses. The awareness levels did demonstrate a geographic trend, where awareness of a number of factors generally increased from north to south. While landuse between the four years did not change significantly and depth to water measurements showed high variability. The region of Amman showed increases in water levels (up to 60m), while areas near Madaba and the desert to the east showed significant decreases (75m). Analysis of the continuity index for the study showed no significant relationships between fragmentation and water depth. This was unanticipated since previous studies (Fischbach 2000 and Lancaster 1999) demonstrate that fragmentation affects agricultural plot efficiency. As the agricultural plots become less efficient, food insecurity can rise within a country (Nyariki 2011). In Jordan, where arable land is at a premium, it is important to maximize efficiency to maintain both a stable food supply as well as, conserve as much water as possible.

**Recommendations**

As the research has demonstrated, awareness of water issues was generally low when compared to some other countries. The Ministry of Water and Irrigation (2002) understands the lack of understanding about the value of scarcity of water resources and the need for raising public awareness about water issues and has instituted 4 points in regards to this:

1. *The public shall be educated through various means about the value of water for them and the well being of the country for the sustainability of life, and for the economic and social development.*
2. *Challenges in the water sector are to be faced not only by the water administration, but also equally by the public if not more. The roles in water conservation to be played by different sectors of society shall be defined and assigned.*

3. *Facts about water in Jordan shall be disseminated along with the cost incurred to provide the service and the mounting pressure of population on water resoures. Introduction, adoption and use of water saving and recycling systems and devices shall be promoted.*

4. *Economic measures shall be adopted to reinforce public awareness. Such measures as demand management, efficiency improvements within supply management techniques shall be employed.*

Although the aforementioned points serve as general guidelines, a comprehensive strategy needs to be developed and implemented in order to safe guard Jordan's water reserves. The survey data in this research suggests that education was a significant factor in understanding water issues. So to expand on this, an education program needs to be developed specifically to focus on water awareness that needs to be implemented at the grade school level across the region or country.

To further the goal of raising public awareness, a television ad campaign could be implemented explaining issues such as desertification, climate change, and water scarcity. Along with this campaign, community programs can be developed, in the form of classes being administered at mosques throughout the country. This would have to be a cooperative effort between government officials and the religious community. The primary reason to facilitate these programs at mosques and churches is due to the centralization of people that occurs during prayer times.

As a leading global producer of phosphate ore, Jordan could leverage this resource into favorable trade agreements to gain new technologies. Demand for phosphate fertilizer is growing due to increasing demand for food in China and India (Warren 2008). The increase in price may allow for imports of new technologies designed to alleviate the water shortages. For example, if world prices of phosphate ore are high enough, the income garnered could be enough to help to establish and maintain a desalinization plant near Aqaba or fund research for newer technologies. Another way to use phosphate ore is to export it in return for agricultural products. This would allow irrigation levels to decline in turn causing an easing of stress to the aquifer.

Joint cooperation with neighboring countries should be initiated in regards to developing new technologies. It is in the regions interest to share technological resources in regards to water conservation. This may alleviate the likelihood of conflict breaking out due to water shortages in two ways. First it can extend the limited resource for those involved. Secondly, if governments are coming together for developing technologies, they may prolong peaceful dialog in the case that conflict over resources arises, as they look for a solution to any water crisis.

The Ministry of Water and Irrigation has a number of plans and policies they are working on in regards to curbing water usage. There has been a rationing of water to the greater Amman area for municipal services since the early 1970's (Haddadin 2006). Water deliveries occur one or two days a week, for up to 4 or 5 hours. This has caused the citizens to purchase oversized storage units to horde water for the week. This water may be susceptible to theft or tinkering if not secured properly.

Well drilling with the aim of expanding of ground water abstraction for irrigation purposes became outlawed in 1992 (Haddadin 2006). However government officials found enforcing this difficult. Haddadin (2006) claims a number of reasons such as high turnover of officials, hesitant law enforcement and the general mood of the people. One way to circumvent lack of action is to create a new division within the Ministry of Water and Irrigation whose sole purpose is the application and enforcing of laws pertaining to water usage. Fines and penalties will create revenue to maintain operational status.

Since the early 1980s, the Disi Aquifer was being tapped for municipal industrial, and agricultural purposes for the city of Aqaba (Ministry of Water and Irrigation 2002). This aquifer will be an ancillary water source to the Amman area by means of the Disi water conveyance project. This massive undertaking is currently under construction and is scheduled to be completed by 2013 and the estimated cost is $1 billion. As of August, 2010 the project is 28% complete (Namrouqa 2010) and on schedule. The project will run approximately 325 km from the sandstone Disi aquifers in the south making stopping by Maan, Tafileh, Karak, and Madaba, before reaching the Amman municipal area in the north(Namrouqa 2010). The project will give access of an estimated 100 MCM of water a year to the Amman Municple area(Saudi Economic Survey 2009). 55 water generation wells will be dug at a depth of 600-700 m to abstract water from the aquifer.

Although the introduction of this water to the Amman-Madaba area will result in needed relief, there are a number of problems associated with it. First, the Disi is a fossil aquifer and has no way to renew itself. The supply of water is expected to be sustainable at this level for only 50 years (Ratcliffe 2010) as population growth remains constant. As it is, this is just a stop gap measure.

Further complicating the usage of the Disi aquifer is the fact that this aquifer is shared between both Jordan and Saudi Arabia. As of 1992, Jordan accused Saudi Arabia of mismanaging the aquifer and over-extracting water for subsidized agricultural practices (Shapland 1997). As water levels decrease in the aquifer, the risk of conflict increases between nations that share this resource. There is also concern that the recent corruption scandals that have taken place in the kingdom may hamper construction of the conveyance project (Kheetan 2011). These scandals have caused the reshuffling of a number of significant positions in the Jordanian government (Al Kaladi 2011) which may cause further delays.

Another potentially hazardous issue is that high levels of naturally occurring radiation were found in the Disi Aquifer (Vengosh et al 2009). In this study, it was reported that levels of carcinogenic radium isotopes are 2000% higher than international drinking water standards. The water has been used in municipal settings in southern Jordan, however, this new study has caused a controversy that has not halted the Disi Project.

Another potential new water source may be the Red Sea to Dead Sea water conveyance. This is a proposed tri-lateral project that is funded by the World Bank that would involve the Israeli and Jordanian governments, as well as the Palestinian Authority. The length of the project is 160 km from the Gulf of Aqaba to the Dead Sea and will allow up to 2000 MCM annually for water level replenishment (Picow 2010). The project also proposes desalinization plants that will provide an estimated 850 MCM of water will be divided between the 3 states involved, as well as hydroelectric power stations that will power the desalinization plants. The project is estimated to cost $15 billion and be completed within 20-27 years (Picow 2010).

Similarly to the Disi conveyance project, this project also has a number of detractors. El-Atrash et al. (2008) points out that the proposed path of the pipeline will go over the Eastern Aquifer system (the west bank's main aquifer) and this raises the probability that any leaked salt water will contaminate that aquifer. Another concern pertains to the mixing of the two water types based on chemistry. Test pools show that different proportions of water affect the chemistry differently. A pool with 70% of water from the Dead Sea and 30% from the Red Sea has been deemed to be conducive for white algae growth. Another test pool, with a 50-50 split shows signs of a red bacteria growing in it (Sherwood 2010).

**Summary**

This study has demonstrated the extent of depletion that irrigation has on groundwater resources in the Madaba Plain and has discussed the possible steps needed to help alleviate the increasing strains on water. In conjunction to the physical landscape of the region, the survey data reveal interesting and important trends in awareness that can help to create sound water conservation policies. Although cross tabulations of land use and ground water maps did not show any significant trends, the methods used can still be beneficial for resource conservation, understanding, and perception.

All living organisms have the ability to sense and avoid harmful environmental conditions (Slovic 1987), and as such understanding perception is key to this study. Awareness of desertification, water mining, and water quality and the other factors need to be examined in conjunction with the physical changes taking place in order to create a more comprehensive policy focused on conservation of both water and land resources.

Surveys such as the one administered in this research will help to measure people's awareness about a number of water issues, and may help authorities to expand educational efforts. Similarly, land use and groundwater depth maps can help to show and explain if any unauthorized use of groundwater is taking place. It also may be used to regulate where irrigated agriculture should take place by comparing it to the groundwater depths, which allows for the area of the aquifer to recover. Finally, groundwater maps may also be used to ascertain where artificial aquifer recharge should take place if the cost is not prohibitive. This will help to reduce the water mining phenomena which will assist with conserving groundwater storage capacity.

With global water concerns at a critical point, it is important to understand the water situation in Jordan and this research was innovative in linking actual water use to perceived water use.  Research into the water issues for this country are of the utmost significance. Understanding the awareness of hazards associated with overuse of water and land can help mitigate overuse through policy changes. Furthermore, better management of aquifer recharge can be ascertained from cross examining land use practices with aquifer depth levels, while an understanding of social perceptions is crucial in linking behavior to water use and water resource quality and quantity.  Jordan requires 1.15 billion cubic meters of water per year, but only 850 million cubic meters of renewable water resources are available (Embassy of Jordan 2011). With water availability at approximately 140$m^3$ per person per year, Jordan is one of the most water-deprived countries in the world (Denny et al. 2008).  The scarcity of water is very concerning as the instability it may cause could have regional effects.  Research must be continued as since water deficiencies and misuse can destabilize a country such as Jordan, that is one of the few signatories of a peace treaty with Israel.  Water resources are increasingly a factor in regional and global peace initiatives and can no longer be overlooked.

## Chapter 8: Works Cited


Abbas, A. 1989. Introduction to the Zarqa River Basin Project in Jordan. *Resource conservation and desertification control in the Near East*, Berlin: Deutsche Stiftung fuer Internationale Entwicklung. Page 263-269.

Al-Adamat, R., and Baban, S. 2004. Mapping Groundwater Level and Depth in the Azraq Basin in Jordan using GIS. *Surveying and Land Information Science* vol. 64 no. 2 pp. 97-105.

Al Khaladi, S. 2011. Jordan‟s prime minister, facing slow economic growth and corruption scandals, reshuffles cabinet. *Al-Arabiya*. July 2, 2011.

Alsharhan, A and Nairn, A. (1997) *Sedimentary Basins and Petroleum Geology of the Middle East*. Elsevier.

Amery, H. 2001. Islam and the Environment. *Water Management in Islam*. International Development Research Center, Ottawa.

Anastasi, A., 1982. *Pyschological testing* 5th ed. New York: Macmillan.

Arnell, N. 1996. *Global Warming, river flows and water resources.* Wiley, West Sussex, U.K.

Aswad, B. 1971. *Property control and social strategies: settlers on a Middle Eastern Plain*, University of Michigan: Ann Arbor.

Attia, B. 2005. Public private partnerships, in: E. Baroudy, A. Abid Lahlou & B. Attia (Eds). *Managing Water Demand: Policies, Practices and Lessons from the Middle East and North Africa Forums.* Available at http://www.irdc.ca/en/ev-88796-201-1-DO_TOPIC.html.

Bainbridge, D. 2007. *A Guide for Desert and Dryland Restoration: New Hope for Arid Lands.* Island Press, Washington.

Bar Matthews, Ayalon, A., and Kaufman, A. 1996. Late Quaternary Paleoclimate in the Eastern Mediterranean Region from Stable Isotope Analysis of Speleothems at Soreq Cave, Israel. *Quaternary Research.* Vol. 47 pp. 155-168.

Bar-Matthews, M., Ayalon, A., Kaufman, A. and Wasserburg, G. 1999. The Eastern Mediterranean Paleoclimate as a Reflection of Regional Events: Soreq cave, Israel. *Earth and Planetary Science Letters* Vol 166. p. 85-95.

Bartov, Y., Goldstein, S., Stein, M., Enzel, Y. 2003. Catastrophic Episodes in the Eastern Mediterranean Linked with the North Atlantic Heinrich events. *Geology*. V. 31, no. 5 p. 439-442.

Bar-Yosef, O. 2000. The Impact of Radiocarbon Dating on Old World Archaeology: Past Achievements and Future Expectations. *Radiocarbon*. Vol. 41 No. 1. p. 23.

Bar-Yosef, O. 1996. The Impact of Late Pleistocene-Early Holocene Climactic Changes on Humans in Southwest Asia. *Humans at the End of the Ice Age:archaology of Pleistocene-Holocene Transition*. New York: Plenum Press.

Batáry, P., Báldi, A. 2004. Conservation Focus Evidence of an Edge Effect on Avian Nest Success. *Conservation Biology*, Apr2004, Vol. 18 Issue 2

Bender, F. (1974). *Geology of Jordan*. Berlin. Stuttgart. Gebrueder.Page 188 figure 160.

Boggett, A. D., Mapplebeck, N. J. and Cullen, R. J. 2000. South Shore Cliffs, Whitehaven: geomorphological survey and emergency cliff stabilization works. Q. J *Engng Geol. Hydrgeol*. Vol. 33 p. 213-226.

Bolstad, P. 2002. *GIS Fundementals*. White Bear Lake, MN: Eider Press.

Bou-Zeid, E. and El-Fadel, M. 2002. Climate Change and Water Resources in Lebanon and the Middle East. *Journal of Water Resources Planning and Management.* Vol. 128. No. 5. p. 343-355.

Bouwer, H. (1999). Artificial recharge of groundwater: systems, design and management. In: Mays LW (ed) *Hydraulic design handbook*. McGraw-Hill, New York.

Brett-Crowther, M.R. 2008. Water, Society and the Future. *International Journal of Environmental Studies.* Vol 65, No. 3 pp. 465-473.

Brice, W. 1978. *The Environmental History of the Near and Middle East Since the Last Ice Age*. London. Academic Press.

Bronger, A. and Sedov, S. 2003. Vetusols and paleosols: natural vs. man-induced environmental change in the Atlantic coastal region of Morocco. *Quaternary International* 106-107. Pp33-60.

Brooks, D.B. 1997. Between the Great Rivers: Water in the Heart of the Middle East. *Water Resources Development*. Vol 13, No. 3, 291-309.

Bruch, C., Altman, S., Al-Moumin, M., Troell, J., Roffman, E. 2007. Legal Frameworks governing Water in the Middle East and North Africa. *Water Resources Development*. Vol. 23, No. 4 pp 595-624.

Burgess, T.M. and *Webster*, R. 1980. Optimal interpolation and isarithmic mapping of soil properties The semi-variogram and punctual kriging. *The journal of Soil Science*. Vol 31, No. 2 p. 315-331.

Butzer, K.W. 1957. Mediterranean Pluvials and the General Circulation of the Pleistocene. *Geografiska Annaler.* Vol. 39, No. 1. p.48-53.

Butzer, K.W. 1958. The near East during the Last Glaciation: A Paleogeographical Sketch. *The Geographical Journal*, Vol. 124, No. 3 p.367-369.

Christensen, L and Ruch, R. 2007. The Effect of Social Influence on response to Hurricane Warnings. *Disasters.* Vol 4, Iss 2. pp 205-210.

Central Intelligence Agency, 2009. The CIA World Factbook, Skyhorse Publishing; 1st Edition.

Cressie, N. 1989. Geostatistics. *The American Statistician.* Vol. 43, No. 4 pp. 197-202.

Cruden, D. M. and Fell, R . (eds). 1997. Landslide Risk Assessment : *Proc.Int. Workshop Landslide Risk Assessment, Honolulu*, Feb.1 9th-21st. Rotterdam: Balkema

Cutter, S., and Borden, K. 2009. Tracking Death. I*ndustrial Engineer: IE*. Vol. 41 Iss. 3, p17.

Dal Santo, D.J. and El-Naser, H. 2001. Policy Reforms and Strategic Planning tools for Water Resources Management: The Hashemite Kingdom of Jordan. *Hydrological Science and Technology.* Vol. 17, No. 1-4. pp 91-105.

Dayan,U. and Morin,D. 2006. Flash flood-producing rainstorms over the Dead Sea: A review. *New Frontiers n Dead Sea Paleoenvironmental Research*. The Geological Society of America.

Denny, E., Donnelly, K., McKay, R., Ponte, G., and Uetake, T. 2008. Sustainable Water Strategies for Jordan. *International Economic Development Program.* Gerald R. Ford School of Public Policy University of Michigan, Ann Arbor.

Drenge, H.E. *Desertification of Arid Lands*. Chur: Hardwood Academic Publisher.

Dunlap, L.E. and Spinazola, J.M. 1981. *Hydrological maps of Ogallala aquifer, west-central Kansas*. USGS Open File Report 81-0039, Lawrence, KS.

Evenari, M., Shannan, L. and Tadmor, N. 1971. *The Negev: the Challenge of Desert*. Harvard University Press: Cambridge.

El-Atrash, A., Salem, H., Isaac, J. 2008. Disaster Mitigation Towards Sustainable Development in the Occupied Palestinian Territories. *AIP Conference Proceedings*, Vol. 1020 Issue 1, p1934-1942, 7/8/2008.

El-Baz, F. and Hassan, M.H.A. 1986. *Physics of Desertification*. Martinus Nijhoff Publishers, Dordrecht.

Embassy of Jordan. 2011. “Information Bureau: Environment and Water.” Washington, D.C.: Embassy of the Hashemite King of Jordan.
http://www.jordanembassyus.org/new/jib/factsheets/environment.shtml

Faruqui, N.I. 2001. Islam and Water Management: Overview and Principles, in: N.I. Faruqui, A.K. Biswas and M.J. Bino (Eds.) *Water Management in Islam*. Available at http://www.idrc.ca/en/ev-9425-201-1-DO_TOPIC.html.

Firestone, Y. 1981. “Land Equalization and Factor Scarcaties: Holding Size and Burden of Impositions in Imperial Central Russia and the Late Ottoman Levant”. *Journal of Economic History*. December 1981 813-833.

Fischbach, M.R. 2000. *State, Society, and Land in Jordan*. Koninklijke Brill NV, Leiden, The Netherlands.

Fischbach, M.R. 2001. *Britain and the Ghawr Abi [ayin ]Ubayda Waqf Controversy in Transjordan*. International Journal of Middle East Studies (2001), 33:4:525-544 Cambridge University Press.

Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S. and Keeney, R.L. 1981. *Acceptable Risk.* Cambridge University Press. New York.

Freud, S., 1929 *Introductory Lectures On Pycho-Analysis*. George Allen & Unwin, London.

Frumkin, A., Magaritz, M., Carmi, I., and Zak, I. 1991. The Holocene Climatic Record of the Salt Caves of Mount Sedom, Israel. *The Holocene.* Vol. 1, Iss 3. pp. 191-200.

Gamanya, R., De Maeyer, P., De Dapper, M. 2009. Object-oriented change detection for the city of Harare, Zimbabwe. *Expert Systems with Applications.* Vol 36. pp. 571-588.

Garnaut, R. 2008. *The Garnaut Climate Change Review.* Cambridge University Press. Melbourne.

Gasse, F. 2000. Hydrological changes in the African tropics since the Last Glacial Maximum. *Quaternary Science Review*. Vol 19. 189.

Goudie, A. 2000. The *Human Impact on the Natural Environment*. (5th ed.). Oxford: Blackwell.

Greiner, R., Patterson, L., and Miller, O., 2009. Motivations, Risk Perceptions and the Adoption of Conservation Practices by Farmers. *Agricultural Systems*. P 86-104.

Haddadin, M.J. 2000. Water Issues in Hashemite Jordan. *Arab Studies Quarterly*. Vol. 22, No. 2 Spring 2000, pp 63-77.

Haddadin, M.J. 2006. *Water Resources in Jordan:Evolving Policies for Development, the Environment, and Conflict Resolution.* RFF Press, Washington.

Hammad, M. 1995. Photovoltaic, wind and diesel: A cost comparative study of water pumping options in Jordan. *Energy Policy*. Vol. 23, Iss. 8 pp 723-726.

Hamrick, J., Aldrich, P. 1998. Reproductive Dominance of Pasture Trees in a Fragmented Tropical Forest Mosaic. *Science*, 07/03/98, Vol. 281 Issue 5373.

Harlan, J. 1985. The Early Bronze Age Environment of Southern ghor and Moab Plateau. *Studies in the History and Archaeology of Jordan II.* Edited by A. Hadidi. P 125-129. Department of Antiquity, Jordan.

Hartman, B. and Boyce, J. 1987. *Needless Hunger: Voices from a Bangladesh Village. Institute for Food and Development Policy*, San Francisco.

Heider, F. 1958. *the Psychology of Interpersonal Relationships*. Erlbaum Associates Publishing.

Hijlawi, T. 2003. Economics and Management of the Use of Different Water Qualities in Irrigation in the West Bank. *Farming and Rural Systems Economics.* Vol. 50. Edited by W. Doppler and S. Bauer. Weikersheim, Germany: Margraf Verlag.

Hillel, D. 1991. Out of the Earth. Civilization and the Life of the Soil. The Free Press, New York.

Home, R. 2006. *Scientific survey and land settlement in British colonialism, with particular reference to land tenure reform in the Middle East 1920-50*. Planning Perspectives, Vol 21. Iss. 1 pp 1-22.

Ingram, J., Fry, P., and Mathieu, A. 2008. Revealing different forms of knowledge held by agricultural scientists and farmers in the context of soil protection and management. Land Use Policy Vol 27.

Issar, A. 1995. Clmatic Change and the History of the Middle East. *American Scientists*. Vol. 83 No. 4 p. 350-355.

Issar, A. and Yakir, D. 1997. Isotope from Wood Buried in the roman siege Ramp of Masada, the Roman Periods Colder Climate. *Biblical Archaeologist* Vol. 60 p. 101-106.

Ittelson, W.H. 1960. *Visual Space Perception*. Springer, New York.

Jastrow, M.J. 1921 An Assyrian law code. *Journal of the American Oriental Society*, 41, pp 1-59.

Javed, M., Khurshid, W., Hassan, I., Raza, M., Ali, A., Baig, A. 2011. An Analysis of Productive Efficiency of Smallholder Farms of Cotton-Wheat Systems in Punjab, Pakistan. *Journal of Agricultural Research.* March 2011. Vol. 49. Iss. 1. Pp. 109 -124.

Jenson, J.R. 2000. *Remote Sensing of the Environment: An Earth Resource Perspective*. Prentice Hall, Inc. NJ. pp 364.

Jordan Natural Resources Authority. 1996. Simplified Geologic Map of Jordan.

Jung, C.G., 1944, *Psychological Types*. Kegan, Paul, Trench, & Trubner, London.

Katzenelson, E., Buium, I., Hillel, S., 1976. Risk of Communicable Disease Infection Associated with Wastewater Irrigation in Agricultural Settlements. *Science*, New Series, Vol. 194, No. 4268 (Nov. 26, 1976), pp. 944-946

Kettle, N., Harrington, L. and Harrington, J. jr., 2007. Groundwater Depletion and Agriucutlural Land Use Change in the High Plains: A Case Study from Wichita County, Kansas. *The Professional Geographer*. Vol. 59 Issue 2. pp 221-235.

Keyder, C. and Tabak, F. 1991. *Landholding and Commercial Agriculture in the Middle East*. State University of New York Pr.

Kheetan, T. 2011. Protesters call for fighting corruption, speeding up political reforms. *The Jordan Times.* April 17, 2011.

Khordish, A. 2004. *Islamic Insurance: a modern approach to Islamic banking*. RoutledgeCurzen, London.

Kimberly, A., Crist, T. 1995.Critical Thresholds in Species" Responses to Landscape Structure. *Ecology.* Vol. 76, No. 8 Dec., 1995.

Komar, P., McManus, J., Styllas, M. 2004. Sediment Accumulation in Tillamook Bay, Oregon: Natural Processes vs. Human Impacts. *The Journal of Geology.* Chicago: Jul 2004. Vol. 112, Iss. 4.

Kouchoukos, N., 2001. Satellite Images and Representations of Near Eastern Landscapes. *Near Eastern Archaeology.* Vol 64. Iss. 1. Pp 80-91.

Lancaster, W and Lancaster, F. 1999. *People, Land and Water in the Arab Middle East: Environments and Landscapes in the Bilad ash-Sham*. Overseas Publishers Association, Amsterdam, The Netherlands.

Lowdermilk, W. 1944. *Palestine, Land of Promise*. Victor Gollancz, London.

Lucke, B., Schmidt, M. 2007. Past and present desertification in the context of climate change- a case study from Jordan. *Forum der Forschung.* Vol. 20 BTU Cottbus p. 85-88

MacArthur, R, Wilson, E. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey.

Maher, L. 2005. The Epipaleolithic in context: paleolandscapes and prehistoric occupation in Wadi Ziqlab, Northern Jordan. Dissertation, Department of Anthropology, University of Toronto.

Mainguet, M. 1994. *Desertification: Natural Background and Human Mismanagement*. Berlin: Springer-Verlag.

Majdalawi, M. (2003). Socio-economic Impacts of the Re-use of Water in Agriculture in Jordan. *Farming and Rural Systems Economics.* Vol. 51. Edited by W. Doppler and S. Bauer. Weikersheim, Germany: Margraf Verlag.

Martens, R. 2001. Freiberg On-line Geoscience. Vol 5.

McCorriston, J. 1991. The Ecology of Seasonal Stress and the Origins of Agriculture in the Near East. *American Anthropologist*. Vol. 93 No. 1 p. 46-89.

Myers, J. L. and Well, A. D. 2003.. *Research Design and Statistical Analysis* (second edition ed.). Lawrence Erlbaum.

Middle East Water Data Banks Project. 2009. *Overview of Middle East Water Resources.* http://exact-me.org/overview/toc.htm.

Mikesell, M.W. 1969. The Deforestation of Mount Lebanon. *The Geographical Review.* Vol. 59. No. 1.

MWI. 2007. Personal Correspondence and data acquisition from the Ministry of water and Irrigation headquarters in Amman, Jordan.

MWI. 2002. *Jordan's Water Strategy*. Ministry of Water and Irrigation, Amman, Jordan.

Moore, A.M.T. and Hillman, G.C. 1992. The Pleistocene to Holocene Transition and Human Economy in the Southwest Asia: The Impact of the Younger Dryas. *American Antiquity.* Vol. 57, No. 3, 482-494.

Morris-Gorring, A. and Belfer-Cohen, A. 1998. The Articulation of Cutural Processes and Late Quaternary Environmental Changes in Cisjordan. *Paleorient.* Vol 23 No. 2 p. 71-93.

Namrouqa, H. 2010. Disi Project construction in Full Force. *The Jordan Times.* August 10, 2010.

Namrouqa, H. 2009. Kingdom braces for drought like conditions. *The Jordan Times*. February 1, 2009.

NOAA. 1997. Data from National Snow and Ice Data Center, National Oceanic & Atmospheric Administration, U.S. Department of Commerce, GISP2 Bidecadal Oxygen Isotope Data.

Nyariki, D. 2011. Farm Size, Modern Technology Adoption, and Efficiency of Small Holdings in Developing Countries: Evidence from Kenya. *Journal of Developing Areas.* Fall 2011, Vol. 45 Iss. 1, p 35-52.

Oliver-Smith, A. (1996). Anthropological Research on Hazards and Disasters. *Annual Review of Anthropology*. Vol. 25 p. 303-328

O"Sullivan, D. and Unwin, D. 2003. *Geographic Information Analysis*. John Wiley and Sons, Inc., Hoboken, New Jersey.

Paradise, T.R. 2005. Perception of earthquake risk in Agadir, Morrocco: A case study from a Muslim community. *Environmental Hazards*. Vol 6. p 167-180.

Paradise, T. R. 2002. Map Series of Jordan for the Royal Geographic Center of Jordan, Amman, Jordan.

Picow, M. 2010. Raising the Dead: Is the „Red-Dead Sea Conveyance Project" Viable?. *The Jerusalem Post*. 07/23/2010.

Rabin, A. and Galili, E., 1985. Recent Maritime Archaeological research in Israel- a preliminary report. *The International Journal of Nautical Archaeology and Underwater Exploration*. Vol. 14. Iss. 1. pp 332-349.

Ratcliffe, V. 2010. Enusring Water Supply. *MEED: Middle East Economic Digest*. Vol 54. Iss. 16. 4/16/2010.

Redman, C.L. 1999. Human Impacts on Ancient Environments. University of Arizona Press, Tucson.

Renn, O. and Rohrman, B. 2000. *Cross-cultural risk perception: a survey of empirical studies*. Kluwer Academic publishers. Dordrecht, Netherlands.

Rosen, A. 1997. Environmental Change and Human Adaptational Failure at the End of the Early Bronze Age in Sothern Levant. *Third Millennium BC climate Change and Old World Collapse*. p. 25-38. Springer, NATO ASI 49, Berlin.

Rossignol-Strick, M. 1999. The Holocene Climatic Optimum and Pollen records of sapropel 1 in the eastern Mediterranean 9000-6000 BP. *Quaternary Science Reviews*. Vol 18 p. 515-530.

Sallaku, F., Tota, O., and Huqi, B. 2007. The agricultural land suitability assessment as the main factor for land consolidation activities in Albania. *2007 Prague Regional Workshop on EU Rural Development Programme 2007-13 and its application to land consolidation.*

Sattler, C. and Nagel, U.J. 2010. Factors affecting farmers" acceptance of conservation measures- A case study from north-eastern Germany. *Land Use Policy*. Vol 27.

Saudi Economic Survey, 2009. Disi Water Conveyance Project. *Saudi Economic Survey*. Jedah. August 12, 2009.

Schmidt, M., Lucke, B., al-Saad, Z., Baumler,R., al-Qudah, B., and Hutcheon, A. 2006. The Decapolis region (Northern Jordan) as a historical example of desertification? Evidence from soil development and distribution. Quaternary International. Vol 151, Pp 74-86.

Shapland, G .1997. SOAS Conference "Water in the Middle East: legal, political, and commercial implications. 19 and 20 November 1992.

Sherwood, H. 2010. Plan to pump water into Dead Sea makes environmentalist see red. http://www.guardian.co.uk/environment/2010/jun/20/plan-pump-water-dead-sea-environmentalists-red. 6/20/2010.

Shoshana, M. 2002. Landscape fragmentation and soil cover changes on south- and north-facing slopes during ecosystems recovery: an analysis from multi-date air photographs.

Shiklomanow, I. 1999. State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris

Slovic, P., Fischhoff, B., and Lichtenstein, S. 1982. Why Study Risk Perception. *Risk Analysis.* Vol 2. No. 2. pp 83-93.

Slovic, P. 1987. Perception of Risk. *Science.* Vol. 236, No. 4799. pp. 280-285.

Stein, M., Torfstein, A., Gavrieli, I., Yechieli, Y. 2010. Abrupt aridities and salt deposition in the post-glacial Dead Sea and their North Atlantic connection. *Quaternary Science Reviews*. Volumer 29, Issue 3-4 pp 567-575.

Sun, Y., Kang, S., Li, F., and Zhang, L. 2009. Comparison of interpolation methods for depth to groundwater and its temporal and spatial variations in the Minqin oasis of northwest China. *Environmental Modelling and Software.* Vol. 24. p.1163-1170.

Taha, S. 2006. The Hashemite Kingdom of Jordan Ministry of Water and Irrigation Country. Paper presented at the Conference of the Wter Directors of the Euro-Mediterranean and South Eastern European, Athens Greece, 6-7 November. Available at http://www.minenv.gr/medeuwi/meetings/conference.of.the.water.directors.athens.6&7-11-06[Country.Reports]_en.html.

The Fund for Peace. 2011. List of Failed States. http://www.fundforpeace.org/global/?q=fsi-grid2011

Thomas, D.S.G. 1997. *Arid Zone Geomorphology: Process, Form and Changes in Drylands* John Wiley & Sons: New York.

United Nations Econimc and Social Commission for Western Asia (UNESCWA). 2003. *The Optimmization of Water Resource Management in the ESCWA Countries: A Survey of Measures Taken by the ESCWA Countries During the 1990s for the Optimization of Water Resource Management and Capacity Building in the Water Sector,* UN Doc. E/ESCWA/SDPD/2003/11.

USGS. 2010. SLC-off Products: Background.
http://landsat.usgs.gov/products_slcoffbackground.php.

USGS. December 5, 2009. Landsat Product Type Descriptions.
http://edcsns17.cr.usgs.gov/helpdocs/landsat/product_descriptions.html#terrain_l5_l1t
*Conservation Biology.* Vol. 9 No. 2. 439-449.

Vengosh, A., Hirschfeld, D., Vinson, D., Dwyer, G., Raanan, H., Rimawi, O., Al-Zoubi, A., Akkawi, E., Marie, A., Haquin, G., Zaarur, S., Ganor, J. 2009. High Naturally Occuring Radioactivity in Fossil Groundwater from the Middle East. *Environmental Science and Technology*. Vol 43. Iss. 6, pp 1769-1775.

Van Dam, J.C. 1999. I*mpacts of climate change and climate variability on hydrological regimes.* Cambridge University Press, Cambridge.

Vogelmann, J.E. 1995. “Assessment of Forest Fragmentation in Southern New England Using Remote Sensing and Geographic Information Information Systems Technology”.
Warriner, D. 1948. *Land and Poverty in the Middle East*. London and New York: Institute of International Affairs.

Warren, M. 2008. Warning of World Phosphate Shortages. *The Austrailian.* 3/12/2008.
Weiss, H. and Bradley, R. 2001. What Drives Societal Collapse? *Science* 291 p. 609-610.

Weiss, H., Country, M.A., Wetterstorm, W., Guichaard, F., Senior, L., Meadow, R., and Curnow, A. 1993. The Genesis and Colapse of Third Millennium North Mesopotamian Civilization. *Science.* Vol. 261 pp. 995-1004.

Wildavsky, A. and Dake, K. (1990). Theories of Risk Perception: Who Fears What and Why? *Daedalus.* Vol. 119, No. 4. pp. 41-6.

Yechieli, Y. 2000. Fresh Saline Ground Water Interface in the Western Dead Sea Area. *Ground Water.* Vol. 38 Issue 4, pp. 615.

## Appendix

**Appendix A-1: Demographic Data**

| ***Respondent*** | ***Location*** | ***Gender*** | ***Land Ownership History*** | ***Marital Status*** | ***Income*** | ***Age*** |
|---|---|---|---|---|---|---|
| 1 | Amman | Male | More then 10 years | Married | <$15,000 | 26-30 years old |
| 2 | Amman | Male | More then 10 years | Married | <$15,000 | 26-30 years old |
| 3 | Um Baseteen | Male | 7-8 years | Married | <$15,000 | 31-35 years old |
| 4 | Um Baseteen | Male | More then 10 years | Married | $15,001-$20,000 | 21-25 years old |
| 5 | Um Baseteen | Male | More then 10 years | Married | $25,001-$30,000 | No Response |
| 6 | Um Baseteen | Male | More then 10 years | Widow/Widower | $20,001-$25,000 | 21-25 years old |
| 7 | Um Baseteen | Female | 7-8 years | Single | $15,001-$20,000 | 31-35 years old |
| 8 | Um Baseteen | Female | More then 10 years | Single | $20,001-$25,000 | > 65 years old |
| 9 | Um Baseteen | Male | 3-4 years | Single | $20,001-$25,000 | 31-35 years old |
| 10 | Um Baseteen | Male | 1-2 years | Married | <$15,000 | 26-30 years old |
| 11 | Um Baseteen | Male | More then 10 years | Widow/Widower | $20,001-$25,000 | < 20 years old |
| 12 | Um Baseteen | Male | More then 10 years | Widow/Widower | <$15,000 | 26-30 years old |
| 13 | Um Baseteen | Male | More then 10 years | Widow/Widower | $20,001-$25,000 | 21-25 years old |
| 14 | Um Baseteen | Female | 5-6 years | Widow/Widower | $25,001-$30,000 | 41-45 years old |
| 15 | Um Baseteen | Male | 1-2 years | Married | <$15,000 | 46-50 years old |
| 16 | Um Baseteen | No Response | 9-10 years | Widow/Widower | $15,001-$20,000 | 26-30 years old |
| 17 | Um Baseteen | Male | More then 10 years | Widow/Widower | $15,001-$20,000 | 26-30 years old |
| 18 | Um Baseteen | Female | 3-4 years | Widow/Widower | >$30,000 | 26-30 years old |
| 19 | Um Baseteen | Male | 9-10 years | Married | <$15,000 | 46-50 years old |
| 20 | Um Baseteen | Male | 9-10 years | Widow/Widower | $15,001-$20,000 | 41-45 years old |
| 21 | Um Baseteen | Female | 5-6 years | Single | $15,001-$20,000 | < 20 years old |
| 22 | Um Baseteen | Male | 3-4 years | Single | <$15,000 | < 20 years old |
| 23 | No Response | Female | 1-2 years | Single | <$15,000 | < 20 years old |
| 24 | Um Baseteen | Male | 5-6 years | Single | <$15,000 | 21-25 years old |
| 25 | Um Baseteen | Male | 3-4 years | Widow/Widower | <$15,000 | < 20 years old |
| 26 | Um Baseteen | Male | 1-2 years | Single | <$15,000 | < 20 years old |
| 27 | Um Baseteen | Male | 5-6 years | Single | <$15,000 | < 20 years old |
| 28 | Um Baseteen | Male | 3-4 years | Single | <$15,000 | 21-25 years old |
| 29 | Um Baseteen | Male | 3-4 years | Married | <$15,000 | < 20 years old |
| 30 | Um Baseteen | Male | 9-10 years | Married | $15,001-$20,000 | 51-55 years old |
| 31 | Um Baseteen | Female | 1-2 years | Single | No Response | < 20 years old |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | Um Baseteen | Male | 5-6 years | Single | <$15,000 | < 20 years old |
| 33 | Um Baseteen | Male | 1-2 years | Married | No Response | < 20 years old |
| 34 | Um Baseteen | Male | 3-4 years | Single | <$15,000 | < 20 years old |
| 35 | Um Baseteen | Female | 5-6 years | Married | No Response | 26-30 years old |
| 36 | Um Baseteen | Male | More then 10 years | Single | $15,001-$20,000 | 51-55 years old |
| 37 | Um Baseteen | Female | More then 10 years | Widow/Widower | $15,001-$20,000 | 36-40 years old |
| 38 | Um Baseteen | Female | 7-8 years | Widow/Widower | $15,001-$20,000 | 51-55 years old |
| 39 | Um Baseteen | Male | 7-8 years | Single | $25,001-$30,000 | 31-35 years old |
| 40 | Um Baseteen | Male | 3-4 years | Single | $15,001-$20,000 | 56-60 years old |
| 41 | Um Baseteen | Male | More then 10 years | Married | $15,001-$20,000 | 56-60 years old |
| 42 | Um Baseteen | Male | 5-6 years | Widow/Widower | $15,001-$20,000 | 51-55 years old |
| 43 | Um Baseteen | Male | 5-6 years | Single | $15,001-$20,000 | 56-60 years old |
| 44 | Um Baseteen | Male | More then 10 years | Married | $25,001-$30,000 | 21-25 years old |
| 45 | Um Baseteen | Male | No Response | Married | No Response | < 20 years old |
| 46 | Um Baseteen | Male | 9-10 years | Married | $20,001-$25,000 | 56-60 years old |
| 47 | Um Baseteen | Female | 1-2 years | Married | $15,001-$20,000 | 56-60 years old |
| 48 | Um Baseteen | Male | 1-2 years | Married | $15,001-$20,000 | 61-65 years old |
| 49 | Um Baseteen | Female | No Response | Single | <$15,000 | 26-30 years old |
| 50 | Um Baseteen | Female | More then 10 years | Married | $20,001-$25,000 | 61-65 years old |
| 51 | Um Baseteen | Male | 5-6 years | Single | $20,001-$25,000 | 56-60 years old |
| 52 | Um Baseteen | Female | More then 10 years | Married | $25,001-$30,000 | > 65 years old |
| 53 | Um Baseteen | Female | 1-2 years | Single | $15,001-$20,000 | 61-65 years old |
| 54 | Um Baseteen | Male | 5-6 years | Married | $20,001-$25,000 | 36-40 years old |
| 55 | Um Baseteen | Male | No Response | Single | $20,001-$25,000 | 56-60 years old |
| 56 | Um Baseteen | Female | 7-8 years | Married | $15,001-$20,000 | 26-30 years old |
| 57 | Um Baseteen | Male | More then 10 years | Widow/Widower | <$15,000 | 61-65 years old |
| 58 | Um Baseteen | Male | 5-6 years | Married | $25,001-$30,000 | 56-60 years old |
| 59 | Um Baseteen | Female | 5-6 years | Married | $25,001-$30,000 | > 65 years old |
| 60 | Um Baseteen | Male | 5-6 years | Married | $15,001-$20,000 | 56-60 years old |
| 61 | Um Baseteen | Male | 1-2 years | Single | $15,001-$20,000 | 56-60 years old |
| 62 | Um Baseteen | Male | 5-6 years | Married | $15,001-$20,000 | 26-30 years old |
| 63 | Um Baseteen | Female | No Response | Married | <$15,000 | 21-25 years old |
| 64 | Um Baseteen | Male | 9-10 years | Single | $20,001-$25,000 | 61-65 years old |
| 65 | Ma'ein | Male | More then 10 years | Married | No Response | 56-60 years old |

| | | | | | | |
|---|---|---|---|---|---|---|
| 66 | Ma'ein | Male | More then 10 years | Married | <$15,000 | 46-50 years old |
| 67 | Ma'ein | Male | More then 10 years | Married | <$15,000 | 51-55 years old |
| 68 | Madaba/Ma'ein | Male | 5-6 years | Married | <$15,000 | 26-30 years old |
| 69 | No Response | Female | More then 10 years | Widow/Widower | <$15,000 | 36-40 years old |
| 70 | Ma'ein | Male | More then 10 years | Married | <$15,000 | 41-45 years old |
| 71 | Ma'ein | Female | More then 10 years | Single | <$15,000 | 31-35 years old |
| 72 | Ma'ein | Female | More then 10 years | Single | No Response | 21-25 years old |
| 73 | Ma'ein | Male | 9-10 years | Widow/Widower | <$15,000 | 31-35 years old |
| 74 | Ma'ein | Male | No Response | Married | No Response | 36-40 years old |
| 75 | Ma'ein | Male | More then 10 years | Single | <$15,000 | 26-30 years old |
| 76 | Ma'ein | Male | More then 10 years | Married | No Response | 41-45 years old |
| 77 | Ma'ein | Female | 7-8 years | Single | <$15,000 | 26-30 years old |
| 78 | Ma'ein | Female | More then 10 years | Single | <$15,000 | 26-30 years old |
| 79 | Madaba | Male | More then 10 years | Married | <$15,000 | > 65 years old |
| 80 | Madaba | Female | More then 10 years | Married | <$15,000 | > 65 years old |
| 81 | Amman | Male | 7-8 years | Married | <$15,000 | 36-40 years old |
| 82 | Amman | Female | More then 10 years | Married | <$15,000 | 26-30 years old |
| 83 | Amman | No Response | 3-4 years | Single | <$15,000 | 31-35 years old |
| 84 | No Response | Female | 5-6 years | Widow/Widower | <$15,000 | No Response |
| 85 | Ma'ein | Male | More then 10 years | Widow/Widower | No Response | 61-65 years old |
| 86 | Ma'ein | Male | 3-4 years | Single | <$15,000 | 26-30 years old |
| 87 | Ma'ein | Male | 5-6 years | Married | No Response | > 65 years old |
| 88 | Al Khatabeyah | Male | More then 10 years | Married | <$15,000 | 61-65 years old |
| 89 | Al Khatabeyah | Male | More then 10 years | Married | <$15,000 | 61-65 years old |
| 90 | El Team | Male | More then 10 years | Married | <$15,000 | 56-60 years old |
| 91 | El Team | Female | More then 10 years | Widow/Widower | <$15,000 | 46-50 years old |
| 92 | El Mareesh | Male | 3-4 years | Married | <$15,000 | 56-60 years old |
| 93 | El Mareesh | Male | More then 10 years | Widow/Widower | <$15,000 | 51-55 years old |
| 94 | El Faysaleyah | Female | 5-6 years | Widow/Widower | No Response | 31-35 years old |
| 95 | El Faysaleyah | Male | 5-6 years | Married | <$15,000 | 31-35 years old |
| 96 | El Faysaleyah | Male | 5-6 years | Married | <$15,000 | 41-45 years old |
| 97 | El Faysaleyah | Male | 9-10 years | Widow/Widower | <$15,000 | 56-60 years old |
| 98 | El Aarish | Male | 1-2 years | Married | <$15,000 | 46-50 years old |
| 99 | El Aarish | Male | More then 10 years | Married | <$15,000 | 31-35 years old |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 100 | El Aarish | Male | More then 10 years | Single | <$15,000 | 26-30 years old |
| 101 | Ma'ein | Female | 5-6 years | Widow/Widower | <$15,000 | 36-40 years old |
| 102 | El Aarish | Male | 9-10 years | Married | <$15,000 | 36-40 years old |
| 103 | El Aarish | Female | 7-8 years | Married | <$15,000 | 36-40 years old |
| 104 | Ma'ein | Male | More then 10 years | Married | <$15,000 | 46-50 years old |
| 105 | Ma'ein | Female | 9-10 years | Widow/Widower | <$15,000 | 41-45 years old |
| 106 | Ma'ein | Male | More then 10 years | Married | <$15,000 | 46-50 years old |
| 107 | Ma'ein | Male | More then 10 years | Married | <$15,000 | 36-40 years old |
| 108 | Madaba | Male | 9-10 years | Widow/Widower | $15,001-$20,000 | 41-45 years old |
| 109 | Madaba | Male | More then 10 years | Widow/Widower | No Response | 51-55 years old |
| 110 | Madaba | Male | 9-10 years | Married | <$15,000 | 41-45 years old |
| 111 | Ma'ein | Female | 7-8 years | Widow/Widower | <$15,000 | 36-40 years old |
| 112 | Ma'ein | Female | 9-10 years | Single | <$15,000 | 36-40 years old |
| 113 | Lib | Female | 3-4 years | Widow/Widower | <$15,000 | 31-35 years old |
| 114 | Lib | No Response | 1-2 years | Married | <$15,000 | 31-35 years old |
| 115 | Lib | Male | 7-8 years | Single | <$15,000 | 31-35 years old |
| 116 | Ma'ein | Male | More then 10 years | Single | No Response | 21-25 years old |
| 117 | Madaba | Male | More then 10 years | Married | <$15,000 | 46-50 years old |
| 118 | Madaba | Female | 9-10 years | Widow/Widower | <$15,000 | 51-55 years old |
| 119 | Madaba | Male | No Response | Married | $25,001-$30,000 | 56-60 years old |
| 120 | Ma'ein | Male | More then 10 years | Married | <$15,000 | 46-50 years old |
| 121 | Madaba | Male | 7-8 years | Married | No Response | 21-25 years old |
| 122 | Madaba | Female | 5-6 years | Single | <$15,000 | 36-40 years old |
| 123 | Madaba | Male | 9-10 years | Married | No Response | 41-45 years old |
| 124 | Madaba | Male | 3-4 years | Married | <$15,000 | 21-25 years old |
| 125 | Madaba | Male | 9-10 years | Married | <$15,000 | 36-40 years old |
| 126 | Madaba | Male | 9-10 years | Single | <$15,000 | 26-30 years old |
| 127 | Madaba | Male | 7-8 years | Married | <$15,000 | 31-35 years old |
| 128 | Madaba | No Response | No Response | Married | No Response | 26-30 years old |
| 129 | Madaba | Male | More then 10 years | Married | <$15,000 | No Response |
| 130 | No Response | Male | 5-6 years | Single | No Response | No Response |
| 131 | No Response | No Response | More then 10 years | Married | No Response | 36-40 years old |

| | | | | | | |
|---|---|---|---|---|---|---|
| 132 | Madaba | Male | 3-4 years | Married | $15,001-$20,000 | No Response |
| 133 | Madaba | Female | 5-6 years | Single | <$15,000 | < 20 years old |
| 134 | Madaba | Male | More then 10 years | Married | <$15,000 | 31-35 years old |
| 135 | No Response | Male | More then 10 years | Married | No Response | 36-40 years old |
| 136 | Madaba | Female | More then 10 years | Single | <$15,000 | < 20 years old |
| 137 | Madaba | Female | 9-10 years | Single | <$15,000 | < 20 years old |
| 138 | Madaba | Male | 3-4 years | Married | No Response | 31-35 years old |
| 139 | Madaba | Female | 9-10 years | Married | $20,001-$25,000 | 26-30 years old |
| 140 | Ma'ein | Male | 1-2 years | Married | <$15,000 | 26-30 years old |
| 141 | Madaba | Male | 9-10 years | Single | No Response | 21-25 years old |
| 142 | Madaba | Female | 7-8 years | Married | No Response | 26-30 years old |
| 143 | Madaba | Female | More then 10 years | Single | <$15,000 | 21-25 years old |
| 144 | Madaba | Female | 7-8 years | Married | <$15,000 | 21-25 years old |
| 145 | Madaba | Female | 3-4 years | Single | <$15,000 | 21-25 years old |
| 146 | Madaba | Female | 5-6 years | Married | $15,001-$20,000 | 26-30 years old |
| 147 | Madaba | Female | 5-6 years | Single | No Response | 26-30 years old |
| 148 | Madaba | Female | 9-10 years | Married | <$15,000 | 31-35 years old |
| 149 | Madaba | Female | 1-2 years | Single | <$15,000 | 21-25 years old |
| 150 | Madaba | Female | 1-2 years | Single | <$15,000 | < 20 years old |
| 151 | Madaba | Female | 3-4 years | Single | $20,001-$25,000 | 21-25 years old |
| 152 | Madaba | Female | 1-2 years | Single | <$15,000 | < 20 years old |
| 153 | Madaba | Female | More then 10 years | Married | No Response | 26-30 years old |
| 154 | Madaba | Male | 9-10 years | Single | $20,001-$25,000 | 21-25 years old |
| 155 | Madaba | Male | More then 10 years | Single | <$15,000 | 21-25 years old |
| 156 | Madaba | Male | 1-2 years | Married | $20,001-$25,000 | 26-30 years old |
| 157 | Amman | Female | More then 10 years | Married | <$15,000 | 31-35 years old |
| 158 | Amman | Female | No Response | Married | <$15,000 | 26-30 years old |
| 159 | Amman | Female | More then 10 years | Married | $15,001-$20,000 | 21-25 years old |
| 160 | Amman | Male | More then 10 years | Single | $15,001-$20,000 | < 20 years old |
| 161 | Amman | Female | More then 10 years | Single | <$15,000 | < 20 years old |
| 162 | Amman | Female | More then 10 years | Single | <$15,000 | < 20 years old |
| 163 | Amman | No Response | More then 10 years | Single | <$15,000 | 21-25 years old |
| 164 | Madaba | Male | 9-10 years | Single | <$15,000 | 26-30 years old |
| 165 | Amman | Male | More then 10 years | Married | <$15,000 | 26-30 years old |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 166 | Amman | Male | More then 10 years | Single | <$15,000 | 21-25 years old |
| 167 | Amman | Female | More then 10 years | Married | <$15,000 | 21-25 years old |
| 168 | Amman | Male | 7-8 years | Single | $15,001-$20,000 | 26-30 years old |
| 169 | Amman | Male | More then 10 years | Single | <$15,000 | 26-30 years old |
| 170 | Amman | Female | More then 10 years | Single | No Response | < 20 years old |
| 171 | Amman | Female | 9-10 years | Single | No Response | 21-25 years old |
| 172 | Amman | No Response | More then 10 years | No Response | <$15,000 | < 20 years old |
| 173 | Amman | No Response | More then 10 years | Single | <$15,000 | < 20 years old |
| 174 | Amman | Female | 1-2 years | Single | $15,001-$20,000 | 26-30 years old |
| 175 | Amman | Female | More then 10 years | Married | $15,001-$20,000 | 31-35 years old |
| 176 | Amman | Female | More then 10 years | Single | $20,001-$25,000 | 21-25 years old |
| 177 | Amman | Female | 9-10 years | Single | $15,001-$20,000 | 26-30 years old |
| 178 | Amman | Female | 3-4 years | Widow/Widower | <$15,000 | 31-35 years old |
| 179 | Amman | Female | 3-4 years | Single | <$15,000 | 21-25 years old |
| 180 | Amman | Female | 7-8 years | Single | No Response | 21-25 years old |
| 181 | Amman | Female | 5-6 years | Single | $15,001-$20,000 | < 20 years old |
| 182 | Amman | Male | 7-8 years | Married | $20,001-$25,000 | 41-45 years old |
| 183 | No Response | Male | 3-4 years | Married | <$15,000 | > 65 years old |
| 184 | Amman | Male | More then 10 years | Married | $20,001-$25,000 | 46-50 years old |
| 185 | Amman | Male | 1-2 years | Married | <$15,000 | 21-25 years old |
| 186 | Amman | Male | More then 10 years | Married | <$15,000 | 61-65 years old |
| 187 | Amman | Male | More then 10 years | Married | <$15,000 | 26-30 years old |
| 188 | Amman | Male | 7-8 years | Married | <$15,000 | 36-40 years old |
| 189 | Amman | Male | 5-6 years | Married | <$15,000 | 31-35 years old |
| 190 | Amman | Male | 9-10 years | Married | <$15,000 | 41-45 years old |
| 191 | Amman | No Response | More then 10 years | Widow/Widower | <$15,000 | 26-30 years old |
| 192 | Amman | Male | No Response | Married | No Response | 26-30 years old |
| 193 | Amman | Male | No Response | Married | <$15,000 | No Response |
| 194 | Amman | Female | 1-2 years | Single | <$15,000 | < 20 years old |
| 195 | Amman | Male | 5-6 years | Single | $15,001-$20,000 | 26-30 years old |
| 196 | Amman | Male | 9-10 years | Married | <$15,000 | 61-65 years old |
| 197 | Amman | Male | 9-10 years | Married | <$15,000 | 36-40 years old |

| | | | | | | |
|---|---|---|---|---|---|---|
| 198 | Amman | Male | No Response | Single | <$15,000 | 31-35 years old |
| 199 | Amman | Male | More then 10 years | Single | $15,001-$20,000 | 21-25 years old |
| 200 | Amman | Male | More then 10 years | Married | <$15,000 | 56-60 years old |
| 201 | Amman | Female | 1-2 years | Single | <$15,000 | < 20 years old |
| 202 | Amman | Male | 7-8 years | Single | <$15,000 | 21-25 years old |
| 203 | Amman | Male | 5-6 years | Married | No Response | 51-55 years old |
| 204 | Amman | Female | 9-10 years | Married | <$15,000 | 26-30 years old |
| 205 | Amman | Male | More then 10 years | Married | $20,001-$25,000 | > 65 years old |
| 206 | Amman | Male | More then 10 years | Single | $15,001-$20,000 | 36-40 years old |
| 207 | Amman | Male | 9-10 years | Widow/Widower | $15,001-$20,000 | 46-50 years old |
| 208 | Amman | Male | 5-6 years | Single | <$15,000 | < 20 years old |
| 209 | Amman | Male | No Response | Married | <$15,000 | 56-60 years old |
| 210 | Amman | Male | 9-10 years | Single | <$15,000 | < 20 years old |
| 211 | Amman | Male | No Response | Married | <$15,000 | 26-30 years old |
| 212 | Amman | Female | 1-2 years | Single | <$15,000 | < 20 years old |
| 213 | Amman | Male | More then 10 years | Single | <$15,000 | 21-25 years old |
| 214 | Madaba | Male | More then 10 years | Single | <$15,000 | < 20 years old |
| 215 | Madaba | Male | 9-10 years | Single | $20,001-$25,000 | 21-25 years old |
| 216 | Amman | Male | More then 10 years | Single | $20,001-$25,000 | 21-25 years old |
| 217 | Amman | Male | More then 10 years | Single | $15,001-$20,000 | 51-55 years old |
| 218 | Madaba | No Response | More then 10 years | Single | <$15,000 | 26-30 years old |
| 219 | Madaba | Male | More then 10 years | Single | <$15,000 | 21-25 years old |
| 220 | Amman | Male | More then 10 years | Single | $20,001-$25,000 | 21-25 years old |
| 221 | Amman | Male | 3-4 years | Single | No Response | > 65 years old |
| 222 | Amman | Male | More then 10 years | Single | $25,001-$30,000 | 21-25 years old |
| 223 | Amman | Female | More then 10 years | Married | <$15,000 | 26-30 years old |
| 224 | Amman | Female | More then 10 years | Single | <$15,000 | 21-25 years old |

## Appendix A-2: Demographic Data Continuation

| ***Participant*** | ***Education*** | ***Employment*** | ***Seasonal Crop Changes*** |
|---|---|---|---|
| 1 | High School | Public Agency | Crop changes later in growing season |
| 2 | High School | Public Agency | Crop changes later in growing season |
| 3 | Some Grad School | Full-Time | Crop changes later in growing season |
| 4 | Masters/PhD | Full-Time | Crop changes later in growing season |
| 5 | Some College | Part-Time | Crop changes later in growing season |
| 6 | Masters/PhD | Part-Time | Crop changes later in growing season |
| 7 | Some College | Self Employed | Crop changes later in growing season |
| 8 | Masters/PhD | Public Agency | Does not Change |
| 9 | Some College | Part-Time | Crop changes later in growing season |
| 10 | Some College | Private Firm | Crop changes later in growing season |
| 11 | High School | Private Firm | Crop changes later in growing season |
| 12 | College Graduate | Part-Time | Crop changes later in growing season |
| 13 | High School | Part-Time | Crop changes later in growing season |
| 14 | Some College | Self Employed | Crop changes later in growing season |
| 15 | Some Grad School | Managerial | Does not Change |
| 16 | Masters/PhD | Part-Time | Crop changes later in growing season |
| 17 | Some College | Part-Time | Crop changes later in growing season |
| 18 | High School | Self Employed | Does not Change |
| 19 | High School | Self Employed | Crop changes later in growing season |
| 20 | Some Grad School | Part-Time | Does not Change |
| 21 | High School | No Response | Does not Change |
| 22 | High School | Full-Time | Does not Change |
| 23 | High School | Part-Time | Does not Change |
| 24 | Some College | Full-Time | Does not Change |
| 25 | High School | Full-Time | Crop changes later in growing season |
| 26 | High School | Managerial | Does not Change |
| 27 | High School | No Response | Does not Change |
| 28 | High School | Full-Time | Does not Change |
| 29 | High School | Managerial | Does not Change |
| 30 | High School | Part-Time | Does not Change |
| 31 | High School | Private Firm | Does not Change |
| 32 | High School | Private Firm | Does not Change |
| 33 | High School | Managerial | Does not Change |
| 34 | Some College | Full-Time | Does not Change |
| 35 | Some College | Part-Time | Does not Change |
| 36 | Masters/PhD | Private Firm | Does not Change |
| 37 | Masters/PhD | Part-Time | Does not Change |
| 38 | College Graduate | Managerial | Crop changes later in growing season |
| 39 | High School | Private Firm | Crop changes later in growing season |
| 40 | Masters/PhD | Public Agency | Does not Change |
| 41 | Masters/PhD | Public Agency | Does not Change |
| 42 | Masters/PhD | Private Firm | Does not Change |
| 43 | Masters/PhD | Public Agency | Does not Change |
| 44 | Masters/PhD | Part-Time | Does not Change |

| | | | |
|---|---|---|---|
| 45 | Masters/PhD | No Response | Crop changes later in growing season |
| 46 | Masters/PhD | Part-Time | Does not Change |
| 47 | Masters/PhD | Self Employed | Does not Change |
| 48 | Masters/PhD | Public Agency | Crop changes later in growing season |
| 49 | Masters/PhD | Self Employed | Crop changes later in growing season |
| 50 | College Graduate | Public Agency | Crop changes later in growing season |
| 51 | Some Grad School | Private Firm | Does not Change |
| 52 | High School | Part-Time | Does not Change |
| 53 | Masters/PhD | Managerial | Does not Change |
| 54 | College Graduate | Private Firm | Does not Change |
| 55 | Some Grad School | Part-Time | Crop changes later in growing season |
| 56 | College Graduate | Public Agency | Crop changes later in growing season |
| 57 | College Graduate | Private Firm | Does not Change |
| 58 | Masters/PhD | Public Agency | Crop changes later in growing season |
| 59 | High School | Private Firm | Does not Change |
| 60 | College Graduate | Full-Time | Does not Change |
| 61 | College Graduate | Part-Time | Does not Change |
| 62 | College Graduate | Public Agency | No Response |
| 63 | College Graduate | Public Agency | Does not Change |
| 64 | Some Grad School | Private Firm | Does not Change |
| 65 | High School | Self Employed | Crop changes later in growing season |
| 66 | College Graduate | Part-Time | Crop changes later in growing season |
| 67 | High School | Self Employed | Crop changes later in growing season |
| 68 | High School | Self Employed | Does not Change |
| 69 | High School | Self Employed | Crop changes later in growing season |
| 70 | College Graduate | Public Agency | Crop changes later in growing season |
| 71 | Some College | Public Agency | Crop changes later in growing season |
| 72 | College Graduate | Self Employed | Does not Change |
| 73 | Masters/PhD | Private Firm | Does not Change |
| 74 | High School | Part-Time | Does not Change |
| 75 | College Graduate | Public Agency | Crop changes later in growing season |
| 76 | High School | Public Agency | Crop changes later in growing season |
| 77 | College Graduate | Managerial | Crop changes later in growing season |
| 78 | College Graduate | Managerial | Crop changes later in growing season |
| 79 | No Response | Private Firm | Crop changes later in growing season |
| 80 | High School | Self Employed | Does not Change |
| 81 | Some Grad School | Public Agency | Crop changes later in growing season |
| 82 | High School | Full-Time | Does not Change |
| 83 | College Graduate | Private Firm | Does not Change |
| 84 | Some College | No Response | Crop changes later in growing season |
| 85 | High School | Self Employed | Does not Change |
| 86 | College Graduate | Part-Time | Crop changes later in growing season |

| | | | |
|---|---|---|---|
| 87 | Some College | Public Agency | Crop changes later in growing season |
| 88 | High School | Managerial | Does not Change |
| 89 | No Response | Managerial | Does not Change |
| 90 | No Response | Public Agency | Does not Change |
| 91 | Some College | Part-Time | Does not Change |
| 92 | High School | Self Employed | Does not Change |
| 93 | High School | Self Employed | Does not Change |
| 94 | No Response | No Response | Crop changes later in growing season |
| 95 | No Response | Public Agency | Crop changes later in growing season |
| 96 | College Graduate | Public Agency | Does not Change |
| 97 | No Response | No Response | Does not Change |
| 98 | High School | Public Agency | Does not Change |
| 99 | High School | Public Agency | Crop changes later in growing season |
| 100 | College Graduate | Public Agency | Crop changes later in growing season |
| 101 | High School | Public Agency | Crop changes later in growing season |
| 102 | Masters/PhD | Public Agency | Does not Change |
| 103 | Some College | Public Agency | Crop changes later in growing season |
| 104 | High School | Self Employed | Does not Change |
| 105 | High School | Self Employed | Does not Change |
| 106 | High School | Public Agency | Crop changes later in growing season |
| 107 | College Graduate | Public Agency | Crop changes later in growing season |
| 108 | No Response | Part-Time | Crop changes later in growing season |
| 109 | Masters/PhD | Public Agency | No Response |
| 110 | High School | Public Agency | Crop changes later in growing season |
| 111 | High School | Self Employed | Does not Change |
| 112 | No Response | Part-Time | Does not Change |
| 113 | High School | Public Agency | Does not Change |
| 114 | Some College | Private Firm | Does not Change |
| 115 | No Response | Part-Time | Does not Change |
| 116 | College Graduate | No Response | Crop changes later in growing season |
| 117 | High School | No Response | Crop changes later in growing season |
| 118 | High School | Self Employed | Crop changes later in growing season |
| 119 | High School | Private Firm | Crop changes later in growing season |
| 120 | High School | Self Employed | Crop changes later in growing season |
| 121 | High School | Self Employed | Does not Change |
| 122 | High School | Self Employed | Crop changes later in growing season |
| 123 | High School | Public Agency | No Response |
| 124 | High School | Private Firm | Crop changes later in growing season |
| 125 | Some College | Self Employed | Does not Change |
| 126 | Some College | Public Agency | Does not Change |
| 127 | Some College | Managerial | Crop changes later in growing season |
| 128 | College Graduate | Public Agency | Crop changes later in growing season |

| | | | |
|---|---|---|---|
| 129 | High School | Self Employed | No Response |
| 130 | No Response | Public Agency | Crop changes later in growing season |
| 131 | High School | No Response | Does not Change |
| 132 | High School | Full-Time | Crop changes later in growing season |
| 133 | High School | Self Employed | Crop changes later in growing season |
| 134 | Some College | Full-Time | Crop changes later in growing season |
| 135 | High School | Part-Time | Does not Change |
| 136 | High School | Part-Time | Crop changes later in growing season |
| 137 | High School | Private Firm | Crop changes later in growing season |
| 138 | High School | Part-Time | Does not Change |
| 139 | Some College | Private Firm | Crop changes later in growing season |
| 140 | High School | No Response | Crop changes later in growing season |
| 141 | Some Grad School | Full-Time | Does not Change |
| 142 | College Graduate | Full-Time | Does not Change |
| 143 | High School | Private Firm | Crop changes later in growing season |
| 144 | High School | Full-Time | Crop changes later in growing season |
| 145 | High School | Private Firm | Crop changes later in growing season |
| 146 | Some College | Private Firm | Does not Change |
| 147 | High School | Self Employed | Crop changes later in growing season |
| 148 | Some College | Full-Time | Does not Change |
| 149 | Some College | Private Firm | Does not Change |
| 150 | High School | Self Employed | Does not Change |
| 151 | High School | Part-Time | Crop changes later in growing season |
| 152 | High School | Self Employed | Crop changes later in growing season |
| 153 | College Graduate | Private Firm | Crop changes later in growing season |
| 154 | College Graduate | Private Firm | Does not Change |
| 155 | High School | Part-Time | Does not Change |
| 156 | Masters/PhD | Public Agency | Does not Change |
| 157 | Some College | Public Agency | Crop changes later in growing season |
| 158 | High School | Public Agency | Does not Change |
| 159 | High School | No Response | Does not Change |
| 160 | High School | Full-Time | Does not Change |
| 161 | High School | No Response | Crop changes later in growing season |
| 162 | High School | No Response | Crop changes later in growing season |
| 163 | High School | No Response | No Response |
| 164 | College Graduate | Public Agency | Crop changes later in growing season |
| 165 | High School | Public Agency | Crop changes later in growing season |
| 166 | High School | Public Agency | Crop changes later in growing season |
| 167 | College Graduate | Full-Time | Crop changes later in growing season |
| 168 | Some College | Part-Time | Crop changes later in growing season |
| 169 | High School | Public Agency | Crop changes later in growing season |
| 170 | College Graduate | Full-Time | Does not Change |
| 171 | College Graduate | Full-Time | Crop changes later in growing season |
| 172 | High School | No Response | No Response |
| 173 | High School | Part-Time | Crop changes later in growing season |

| | | | |
|---|---|---|---|
| 174 | High School | Full-Time | Crop changes later in growing season |
| 175 | High School | Private Firm | Does not Change |
| 176 | High School | Private Firm | Crop changes later in growing season |
| 177 | High School | Private Firm | Crop changes later in growing season |
| 178 | High School | Private Firm | Crop changes later in growing season |
| 179 | Some College | Part-Time | Crop changes later in growing season |
| 180 | High School | Part-Time | Crop changes later in growing season |
| 181 | Some College | Full-Time | Does not Change |
| 182 | High School | Self Employed | Crop changes later in growing season |
| 183 | Some College | Self Employed | Crop changes later in growing season |
| 184 | High School | Self Employed | Does not Change |
| 185 | High School | Self Employed | Does not Change |
| 186 | High School | Private Firm | Crop changes later in growing season |
| 187 | High School | Public Agency | Crop changes later in growing season |
| 188 | High School | Public Agency | Does not Change |
| 189 | High School | Public Agency | Does not Change |
| 190 | High School | Public Agency | Does not Change |
| 191 | Some College | Part-Time | Crop changes later in growing season |
| 192 | High School | Self Employed | No Response |
| 193 | High School | No Response | No Response |
| 194 | High School | Managerial | Does not Change |
| 195 | College Graduate | Part-Time | No Response |
| 196 | High School | Managerial | Crop changes later in growing season |
| 197 | Some College | Self Employed | Does not Change |
| 198 | College Graduate | Part-Time | Does not Change |
| 199 | High School | Public Agency | Does not Change |
| 200 | High School | Self Employed | Does not Change |
| 201 | Some College | Private Firm | Does not Change |
| 202 | High School | Private Firm | Does not Change |
| 203 | Some College | Managerial | Does not Change |
| 204 | High School | Part-Time | Crop changes later in growing season |
| 205 | High School | Self Employed | Does not Change |
| 206 | High School | Private Firm | Does not Change |
| 207 | High School | Full-Time | Does not Change |
| 208 | High School | Self Employed | Does not Change |
| 209 | High School | Self Employed | Does not Change |
| 210 | High School | Self Employed | Crop changes later in growing season |
| 211 | College Graduate | Full-Time | Does not Change |
| 212 | High School | Full-Time | Does not Change |
| 213 | College Graduate | Full-Time | Crop changes later in growing season |
| 214 | College Graduate | Private Firm | Crop changes later in growing season |

| | | | |
|---|---|---|---|
| 215 | No Response | Managerial | Does not Change |
| 216 | College Graduate | Full-Time | Crop changes later in growing season |
| 217 | Masters/PhD | Full-Time | Crop changes later in growing season |
| 218 | College Graduate | Private Firm | Does not Change |
| 219 | College Graduate | Full-Time | Crop changes later in growing season |
| 220 | College Graduate | Self Employed | Crop changes later in growing season |
| 221 | College Graduate | Self Employed | Does not Change |
| 222 | College Graduate | Self Employed | Crop changes later in growing season |
| 223 | College Graduate | No Response | Crop changes later in growing season |
| 224 | High School | Private Firm | Crop changes later in growing season |

# Appendix A-3:  Likert Scale Data

| ***Respondent*** | ***Overpumping Aquifers*** | ***Water Mining*** | ***Water Quality*** | ***Water Runoff*** | ***Desertification*** | ***Methods/Technologies*** | ***Landuse Changes*** |
|---|---|---|---|---|---|---|---|
| 1 | Not Aware | Aware | Aware | Aware | Strongly Aware | No Response | Very Aware |
| 2 | Somewhat Aware | Somewhat Aware | Very Aware | Aware | Very Aware | Not Aware | No Response |
| 3 | Not Aware | Somewhat Aware | Aware | Very Aware | Strongly Aware | Aware | Strongly Aware |
| 4 | Not Aware | Somewhat Aware | Aware | Very Aware | Strongly Aware | Not Aware | Aware |
| 5 | Not Aware | Aware | Strongly Aware | Somewhat Aware | Aware | Very Aware | Aware |
| 6 | Somewhat Aware | Strongly Aware | Aware | Very Aware | Not Aware | Strongly Aware | Strongly Aware |
| 7 | Aware | Strongly Aware | Very Aware | Aware | Somewhat Aware | Not Aware | Aware |
| 8 | Aware | Somewhat Aware | Strongly Aware | Very Aware | Somewhat Aware | Somewhat Aware | Strongly Aware |
| 9 | Very Aware | Not Aware | Somewhat Aware | Strongly Aware | Somewhat Aware | Not Aware | Very Aware |
| 10 | Somewhat Aware | Very Aware | Somewhat Aware | Aware | Strongly Aware | Somewhat Aware | Not Aware |
| 11 | Somewhat Aware | Very Aware | Very Aware | Somewhat Aware | Strongly Aware | Aware | Strongly Aware |
| 12 | Not Aware | Somewhat Aware | Aware | Very Aware | Strongly Aware | Aware | Somewhat Aware |
| 13 | Not Aware | Somewhat Aware | Aware | Very Aware | Strongly Aware | Somewhat Aware | Very Aware |
| 14 | Not Aware | Very Aware | Aware | Not Aware | Somewhat Aware | Not Aware | Not Aware |
| 15 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware |
| 16 | Aware | Somewhat Aware | Aware | Very Aware | Strongly Aware | Aware | Somewhat Aware |
| 17 | Not Aware | Somewhat Aware | Aware | Very Aware | Strongly Aware | Somewhat Aware | Aware |
| 18 | Not Aware | Very Aware | Somewhat Aware | Somewhat Aware | Aware | Not Aware | Not Aware |
| 19 | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Very Aware | Somewhat Aware | Not Aware |
| 20 | Not Aware | Somewhat Aware | Aware | Very Aware | Very Aware | Somewhat Aware | Not Aware |
| 21 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 22 | Not Aware | Somewhat Aware | Somewhat Aware | Very Aware | Somewhat Aware | Somewhat Aware | Not Aware |
| 23 | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Somewhat Aware | Not Aware | Not Aware |
| 24 | Not Aware | Somewhat Aware | Very Aware | Aware | Somewhat Aware | Not Aware | Not Aware |
| 25 | Somewhat Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware |
| 26 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware | Somewhat Aware | Not Aware |
| 27 | Not Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Very Aware | Somewhat Aware | Not Aware |
| 28 | Not Aware | Somewhat Aware | Very Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware |
| 29 | Somewhat Aware | Aware | Somewhat Aware | Not Aware | Somewhat Aware | Not Aware | Not Aware |
| 30 | Somewhat Aware | Somewhat Aware | Aware | Somewhat Aware | Not Aware | Somewhat Aware | Somewhat Aware |
| 31 | Not Aware | Somewhat Aware | Very Aware | Aware | Somewhat Aware | Aware | Aware |
| 32 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware |
| 33 | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware | Not Aware |
| 34 | Somewhat Aware | Very Aware | Aware | Somewhat Aware | Aware | Aware | Somewhat Aware |
| 35 | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware |
| 36 | Not Aware | Aware | Strongly Aware | Not Aware | Very Aware | Somewhat Aware | Not Aware |
| 37 | Very Aware | Aware | No Response | Very Aware | No Response | No Response | No Response |
| 38 | Not Aware | No Response | Somewhat Aware | No Response | No Response | Not Aware | No Response |
| 39 | Somewhat Aware | Aware | Strongly Aware | Not Aware | Very Aware | Aware | Strongly Aware |
| 40 | Not Aware | Strongly Aware | Somewhat Aware | Very Aware | Somewhat Aware | Very Aware | Aware |
| 41 | Not Aware | Aware | Somewhat Aware | Very Aware | Somewhat Aware | Somewhat Aware | Aware |
| 42 | Not Aware | Somewhat Aware | Very Aware | Aware | Strongly Aware | Aware | Very Aware |
| 43 | Not Aware | Aware | Strongly Aware | Somewhat Aware | Very Aware | Somewhat Aware | Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 44 | Somewhat Aware | Very Aware | Aware | Strongly Aware | Not Aware | No Response | No Response |
| 45 | Somewhat Aware | Very Aware | Aware | Not Aware | Very Aware | Somewhat Aware | Very Aware |
| 46 | Not Aware | Aware | Not Aware | Somewhat Aware | Aware | Strongly Aware | Very Aware |
| 47 | Somewhat Aware | Very Aware | Somewhat Aware | Strongly Aware | Aware | Somewhat Aware | Not Aware |
| 48 | Not Aware | Aware | Not Aware | Very Aware | Somewhat Aware | Strongly Aware | Aware |
| 49 | Not Aware | Strongly Aware | Aware | Very Aware | Somewhat Aware | Not Aware | Aware |
| 50 | Somewhat Aware | Very Aware | Not Aware | Aware | Strongly Aware | Very Aware | Strongly Aware |
| 51 | Strongly Aware | Aware | Very Aware | Aware | Not Aware | Very Aware | No Response |
| 52 | Strongly Aware | Not Aware | Aware | Strongly Aware | Somewhat Aware | Not Aware | Not Aware |
| 53 | Somewhat Aware | Very Aware | Aware | Strongly Aware | Not Aware | Somewhat Aware | Aware |
| 54 | Very Aware | Aware | Strongly Aware | Very Aware | Not Aware | Aware | Somewhat Aware |
| 55 | Aware | Not Aware | Very Aware | Somewhat Aware | Aware | Strongly Aware | Somewhat Aware |
| 56 | Not Aware | Aware | Strongly Aware | Somewhat Aware | Very Aware | Not Aware | Aware |
| 57 | Very Aware | Somewhat Aware | Very Aware | Not Aware | Aware | Strongly Aware | Not Aware |
| 58 | Somewhat Aware | Strongly Aware | Very Aware | Strongly Aware | Somewhat Aware | Aware | Not Aware |
| 59 | Not Aware | Aware | No Response | Somewhat Aware | Strongly Aware | Aware | Not Aware |
| 60 | Not Aware | Aware | Somewhat Aware | Aware | Strongly Aware | Aware | Aware |
| 61 | Not Aware | Somewhat Aware | Strongly Aware | Aware | Very Aware | Aware | Aware |
| 62 | Aware | Strongly Aware | Somewhat Aware | Strongly Aware | Aware | Not Aware | Very Aware |
| 63 | Not Aware | Somewhat Aware | Strongly Aware | No Response | Somewhat Aware | Aware | Not Aware |
| 64 | Not Aware | Aware | Somewhat Aware | Very Aware | Somewhat Aware | Aware | Aware |
| 65 | Somewhat Aware | Aware | Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Strongly Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 66 | Aware | Very Aware | Aware | Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 67 | Not Aware | Somewhat Aware | Somewhat Aware | Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 68 | Somewhat Aware | Somewhat Aware | Strongly Aware | Not Aware | Strongly Aware | Aware | Very Aware |
| 69 | Aware | Somewhat Aware | Strongly Aware | Somewhat Aware | Strongly Aware | Aware | Not Aware |
| 70 | Somewhat Aware | Aware | Very Aware | Very Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 71 | Somewhat Aware | Very Aware | Somewhat Aware | Very Aware | Aware | Very Aware | Somewhat Aware |
| 72 | Somewhat Aware | Very Aware | Aware | Somewhat Aware | Strongly Aware | Aware | No Response |
| 73 | Strongly Aware | Very Aware | Strongly Aware | Strongly Aware | Strongly Aware | Aware | Strongly Aware |
| 74 | Very Aware | Aware | Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 75 | Aware | Very Aware | Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 76 | Aware | Very Aware | Somewhat Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 77 | Somewhat Aware | Very Aware | Aware | Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 78 | Aware | Very Aware | Somewhat Aware | Aware | Strongly Aware | Aware | No Response |
| 79 | Somewhat Aware | Not Aware | Very Aware | Not Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 80 | Somewhat Aware | Somewhat Aware | Aware | Not Aware | Strongly Aware | Strongly Aware | Very Aware |
| 81 | Strongly Aware | Very Aware | Not Aware | Aware | Strongly Aware | Very Aware | Somewhat Aware |
| 82 | Aware | Strongly Aware | Very Aware | Strongly Aware | Strongly Aware | Strongly Aware | Very Aware |
| 83 | Not Aware | Aware | Somewhat Aware | Not Aware | Strongly Aware | Very Aware | Very Aware |
| 84 | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware | Very Aware |
| 85 | Not Aware | Aware | Very Aware | Not Aware | Somewhat Aware | Strongly Aware | Aware |
| 86 | Somewhat Aware | Somewhat Aware | Aware | Not Aware | Strongly Aware | Strongly Aware | Very Aware |
| 87 | Somewhat Aware | Aware | Very Aware | Somewhat Aware | Strongly Aware | Very Aware | Somewhat Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 88 | Aware | Very Aware | Strongly Aware | Very Aware | Strongly Aware | Aware | Somewhat Aware |
| 89 | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Strongly Aware | Very Aware | Aware |
| 90 | Not Aware | Somewhat Aware | Very Aware | Aware | Very Aware | Strongly Aware | Strongly Aware |
| 91 | Not Aware | Not Aware | Somewhat Aware | Aware | Aware | Very Aware | Strongly Aware |
| 92 | Not Aware | Not Aware | Very Aware | Aware | Aware | Strongly Aware | Strongly Aware |
| 93 | Not Aware | Somewhat Aware | Aware | Not Aware | Very Aware | Strongly Aware | Very Aware |
| 94 | Not Aware | Somewhat Aware | Aware | Aware | Very Aware | Aware | Strongly Aware |
| 95 | Somewhat Aware | Somewhat Aware | Very Aware | Strongly Aware | Very Aware | Somewhat Aware | Aware |
| 96 | Somewhat Aware | Not Aware | Aware | Very Aware | Strongly Aware | Aware | Strongly Aware |
| 97 | Not Aware | Not Aware | Very Aware | Strongly Aware | Very Aware | Aware | Aware |
| 98 | Somewhat Aware | Strongly Aware | Somewhat Aware | Strongly Aware | Not Aware | Somewhat Aware | Very Aware |
| 99 | Somewhat Aware | Aware | Aware | Somewhat Aware | Somewhat Aware | Very Aware | Very Aware |
| 100 | Aware | Somewhat Aware | Somewhat Aware | Not Aware | Strongly Aware | Very Aware | Very Aware |
| 101 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Very Aware | Very Aware | Very Aware |
| 102 | Aware | Very Aware | Somewhat Aware | Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 103 | Somewhat Aware | Aware | Very Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 104 | Not Aware | Not Aware | Not Aware | Not Aware | Very Aware | Very Aware | Very Aware |
| 105 | Not Aware | Not Aware | Not Aware | Not Aware | Aware | Aware | Somewhat Aware |
| 106 | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Very Aware | Very Aware | Very Aware |
| 107 | Somewhat Aware | Somewhat Aware | Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 108 | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware | Strongly Aware |
| 109 | Somewhat Aware | Not Aware | Not Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 110 | Not Aware | Somewhat Aware | Aware | Very Aware | Strongly Aware | Strongly Aware | No Response |
| 111 | Not Aware | Not Aware | Somewhat Aware | Not Aware | Very Aware | Very Aware | Strongly Aware |
| 112 | Aware | Somewhat Aware | Somewhat Aware | Very Aware | Aware | Strongly Aware | Very Aware |
| 113 | Somewhat Aware | Aware | Strongly Aware | Not Aware | Very Aware | Aware | Somewhat Aware |
| 114 | Somewhat Aware | Not Aware | Very Aware | Somewhat Aware | Strongly Aware | Aware | Aware |
| 115 | Somewhat Aware | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Aware | Strongly Aware |
| 116 | Somewhat Aware | Not Aware | Very Aware | Somewhat Aware | Very Aware | Somewhat Aware | Aware |
| 117 | Not Aware | Somewhat Aware | Strongly Aware | Somewhat Aware | Strongly Aware | Very Aware | No Response |
| 118 | Not Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware | Aware | Very Aware |
| 119 | Aware | No Response | Somewhat Aware | Aware | Strongly Aware | Very Aware | Somewhat Aware |
| 120 | Aware | Somewhat Aware | Somewhat Aware | Not Aware | Not Aware | No Response | Somewhat Aware |
| 121 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Somewhat Aware |
| 122 | Not Aware | Very Aware | Strongly Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Strongly Aware |
| 123 | Somewhat Aware | Not Aware | Very Aware | Aware | Strongly Aware | Strongly Aware | Aware |
| 124 | Somewhat Aware | Aware | Aware | Strongly Aware | Not Aware | Strongly Aware | Very Aware |
| 125 | Not Aware | Aware | Very Aware | No Response | Not Aware | Very Aware | Somewhat Aware |
| 126 | Not Aware | Strongly Aware | Aware | Somewhat Aware | Strongly Aware | Somewhat Aware | Somewhat Aware |
| 127 | Very Aware | Strongly Aware | Strongly Aware | Somewhat Aware | Strongly Aware | Strongly Aware | Somewhat Aware |
| 128 | Somewhat Aware | Aware | Aware | Aware | Not Aware | Not Aware | Not Aware |
| 129 | Somewhat Aware | Somewhat Aware | Somewhat Aware | Aware | Aware | Aware | Aware |
| 130 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware | Not Aware |
| 131 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Aware | Strongly Aware | Somewhat Aware |
| 132 | Somewhat Aware | Somewhat | Aware | Very Aware | Aware | Very Aware | Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Aware | | | | | |
| 133 | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware | Somewhat Aware | Not Aware |
| 134 | Somewhat Aware | Very Aware | Aware | Somewhat Aware | Very Aware | Somewhat Aware | Somewhat Aware |
| 135 | Very Aware | Aware | Aware | Aware | Somewhat Aware | Very Aware | Very Aware |
| 136 | Aware | Somewhat Aware | Very Aware | Somewhat Aware | Aware | Aware | Somewhat Aware |
| 137 | Somewhat Aware | Somewhat Aware | Not Aware | Somewhat Aware | Not Aware | Somewhat Aware | Not Aware |
| 138 | Very Aware | Not Aware | Aware | Very Aware | Aware | Very Aware | Very Aware |
| 139 | Somewhat Aware | Aware | Aware | Somewhat Aware | Very Aware | Aware | Somewhat Aware |
| 140 | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware | Aware | Somewhat Aware |
| 141 | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware | Somewhat Aware | Very Aware |
| 142 | Not Aware | Very Aware | Somewhat Aware | Aware | Very Aware | Aware | No Response |
| 143 | Somewhat Aware | Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Not Aware | Not Aware |
| 144 | Somewhat Aware | Somewhat Aware | Very Aware | Very Aware | Aware | Somewhat Aware | Not Aware |
| 145 | Aware | Somewhat Aware | Very Aware | Aware | Not Aware | Strongly Aware | Somewhat Aware |
| 146 | Very Aware | Not Aware | Very Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Not Aware |
| 147 | Somewhat Aware | Very Aware | Aware | Strongly Aware | Aware | Aware | Strongly Aware |
| 148 | Not Aware | Somewhat Aware | Not Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Not Aware |
| 149 | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware | Somewhat Aware | Not Aware | Not Aware |
| 150 | Somewhat Aware | Aware | Very Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware |
| 151 | Not Aware | Aware | Somewhat Aware | Aware | Very Aware | Very Aware | Somewhat Aware |
| 152 | Somewhat Aware | Aware | Very Aware | Somewhat Aware | Aware | Not Aware | Not Aware |
| 153 | Not Aware | Very Aware | Very Aware | Strongly Aware | Strongly Aware | Very Aware | Strongly Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 154 | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Strongly Aware | Aware | Somewhat Aware |
| 155 | Very Aware | Somewhat Aware | Strongly Aware | Somewhat Aware | Somewhat Aware | Strongly Aware | Somewhat Aware |
| 156 | Not Aware | Somewhat Aware | Somewhat Aware | Aware | Strongly Aware | Aware | Somewhat Aware |
| 157 | Somewhat Aware | Aware | Very Aware | Very Aware | Strongly Aware | Strongly Aware | No Response |
| 158 | Very Aware | Somewhat Aware | Very Aware | Aware | Not Aware | Somewhat Aware | Strongly Aware |
| 159 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Aware | Somewhat Aware |
| 160 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Aware | Somewhat Aware |
| 161 | Not Aware | Not Aware | No Response | Aware | Aware | Very Aware | No Response |
| 162 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware | No Response |
| 163 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Aware | Not Aware | Aware |
| 164 | Somewhat Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Not Aware | Aware | Not Aware |
| 165 | Somewhat Aware | Aware | Not Aware | Somewhat Aware | Very Aware | Not Aware | Not Aware |
| 166 | Somewhat Aware | Not Aware | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Not Aware |
| 167 | Aware | Very Aware | Somewhat Aware | Very Aware | Very Aware | Very Aware | Strongly Aware |
| 168 | Very Aware | Aware | Very Aware | Aware | Strongly Aware | Strongly Aware | No Response |
| 169 | Not Aware | Somewhat Aware | Very Aware | Aware | Very Aware | Aware | Somewhat Aware |
| 170 | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Strongly Aware | Aware | Somewhat Aware |
| 171 | Not Aware | Somewhat Aware | Not Aware | Very Aware | Very Aware | Somewhat Aware | Somewhat Aware |
| 172 | Not Aware | Not Aware | Not Aware | Aware | Somewhat Aware | Not Aware | Somewhat Aware |
| 173 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware | Somewhat Aware |
| 174 | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware |
| 175 | Not Aware | Somewhat | Aware | Strongly Aware | Aware | Aware | Somewhat |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Aware | | | | | Aware |
| 176 | Not Aware | Not Aware | Somewhat Aware | Not Aware | Aware | Somewhat Aware | Somewhat Aware |
| 177 | Not Aware | Somewhat Aware | No Response | Aware | Aware | Somewhat Aware | Not Aware |
| 178 | Not Aware | Not Aware | Somewhat Aware | Aware | Aware | Not Aware | Not Aware |
| 179 | Not Aware | Somewhat Aware | Not Aware | Aware | Aware | Somewhat Aware | Somewhat Aware |
| 180 | Somewhat Aware | Very Aware | Somewhat Aware | Very Aware | Aware | Very Aware | Somewhat Aware |
| 181 | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Very Aware | Somewhat Aware | Somewhat Aware |
| 182 | Not Aware | Not Aware | Somewhat Aware | Very Aware | Somewhat Aware | Very Aware | Aware |
| 183 | Strongly Aware | Aware | Not Aware | Not Aware | Not Aware | Strongly Aware | Somewhat Aware |
| 184 | Aware | Somewhat Aware | Very Aware | Very Aware | Aware | Very Aware | Very Aware |
| 185 | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware |
| 186 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware |
| 187 | Aware | Very Aware | Not Aware | Not Aware | Not Aware | Somewhat Aware | Aware |
| 188 | Not Aware | Not Aware | Not Aware | Aware | Somewhat Aware | Somewhat Aware | Not Aware |
| 189 | Somewhat Aware | Somewhat Aware | Not Aware | Aware | Strongly Aware | Very Aware | Not Aware |
| 190 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Not Aware |
| 191 | Not Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Aware | Somewhat Aware |
| 192 | Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Very Aware | Aware |
| 193 | No Response | No Response | No Response | No Response | No Response | No Response | No Response |
| 194 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware |
| 195 | Somewhat Aware | Aware | Aware | Aware | Very Aware | Strongly Aware | Somewhat Aware |
| 196 | Somewhat Aware | Not Aware | Not Aware | Aware | Aware | Very Aware | Somewhat Aware |
| 197 | Aware | Somewhat | Somewhat | Somewhat | Aware | Not Aware | Somewhat |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Aware | Aware | Aware | | | Aware |
| 198 | Strongly Aware | Strongly Aware | Strongly Aware | Strongly Aware | Very Aware | Very Aware | Very Aware |
| 199 | Somewhat Aware | Somewhat Aware | Somewhat Aware | Aware | Not Aware | Not Aware | Aware |
| 200 | Not Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Aware | Not Aware | Not Aware |
| 201 | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware |
| 202 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Not Aware |
| 203 | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware |
| 204 | Aware | Aware | Very Aware | Somewhat Aware | Somewhat Aware | Very Aware | Somewhat Aware |
| 205 | Aware | No Response | Very Aware | Very Aware | Very Aware | Aware | Somewhat Aware |
| 206 | Somewhat Aware | Aware | Aware | Very Aware | Not Aware | Aware | Aware |
| 207 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Somewhat Aware | Aware | Aware |
| 208 | Not Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware | Not Aware | Not Aware |
| 209 | Not Aware | Not Aware | Not Aware | Somewhat Aware | Not Aware | Not Aware | Not Aware |
| 210 | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware | Somewhat Aware | Somewhat Aware | Not Aware |
| 211 | Somewhat Aware | Somewhat Aware | Somewhat Aware | Very Aware | Aware | Strongly Aware | Very Aware |
| 212 | Somewhat Aware | Not Aware | Very Aware | Somewhat Aware | Somewhat Aware | Somewhat Aware | Very Aware |
| 213 | Somewhat Aware | Not Aware | Not Aware | Somewhat Aware | Aware | Not Aware | Not Aware |
| 214 | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Very Aware | Strongly Aware | Somewhat Aware |
| 215 | Somewhat Aware | Aware | Strongly Aware | Somewhat Aware | Somewhat Aware | Aware | Aware |
| 216 | Somewhat Aware | Aware | Aware | Somewhat Aware | Strongly Aware | Somewhat Aware | Strongly Aware |
| 217 | Aware | Somewhat Aware | Very Aware | Strongly Aware | Strongly Aware | Strongly Aware | Somewhat Aware |
| 218 | Not Aware | Somewhat Aware | Not Aware | Aware | Not Aware | Strongly Aware | Aware |
| 219 | Strongly Aware | Very Aware | Very Aware | Strongly Aware | Strongly Aware | Strongly Aware | Strongly Aware |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 220 | Somewhat Aware | Not Aware | Very Aware | Strongly Aware | Very Aware | Somewhat Aware | Not Aware |
| 221 | Not Aware | Not Aware | Very Aware | Strongly Aware | Strongly Aware | Strongly Aware | Not Aware |
| 222 | Aware | Somewhat Aware | Aware | Strongly Aware | Strongly Aware | Strongly Aware | Somewhat Aware |
| 223 | Not Aware | Somewhat Aware | Aware | Somewhat Aware | Very Aware | Very Aware | Aware |
| 224 | Not Aware | Aware | Strongly Aware | Aware | Very Aware | Not Aware | Not Aware |

# Appendix B - Jenks classifications

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***jenks_86_91*** | -14.1671 | -11.1541 | -9.28886 | -7.56714 | -5.98889 | -4.48238 | -3.04761 | -1.46936 | 0.018063 | 1.68714 | 4.19799 |
| ***jenks_91_98*** | -54.0533 | -33.7708 | -17.5449 | -6.38948 | 1.216448 | 9.329442 | 18.96362 | 29.10486 | 40.76729 | 53.44385 | 75.75458 |
| ***jenks_98_02*** | -74.3197 | -62.851 | -55.6422 | -48.761 | -41.5522 | -33.688 | -25.1684 | -16.6489 | -8.45702 | -0.9205 | 9.565094 |
| ***jenks_02_07*** | -21.5133 | -13.6246 | -9.14727 | -4.88314 | -0.19258 | 4.284762 | 9.614935 | 16.01114 | 22.19414 | 27.0979 | 33.0677 |

## Appendix C - Likert questions and Location

| Location | Awareness | *Overpumping Aquifers* | *Water Mining* | *Water Quality* | *Water Runoff* | *Desertification* | *Methods/Tech* | *Landuse Changes* |
|---|---|---|---|---|---|---|---|---|
| Um Baseteen | not aware | 59.02 | 6.56 | 11.48 | 18.03 | 19.67 | 27.87 | 37.70 |
| Um Baseteen | Somewhat | 22.95 | 40.98 | 26.23 | 24.59 | 29.51 | 29.51 | 11.48 |
| Um Baseteen | aware | 8.20 | 24.59 | 27.87 | 14.75 | 13.11 | 24.59 | 24.59 |
| Um Baseteen | very | 6.56 | 16.39 | 16.39 | 27.87 | 14.75 | 6.56 | 9.84 |
| Um Baseteen | strongly | 3.28 | 9.84 | 14.75 | 11.48 | 19.67 | 8.20 | 9.84 |
| n=61 | no response | 0.00 | 1.64 | 3.28 | 3.28 | 3.28 | 3.28 | 6.56 |
| | | | | | | | | |
| Main | not aware | 26.92 | 19.23 | 11.54 | 30.77 | 3.85 | 0.00 | 0.00 |
| Main | Somewhat | 42.31 | 26.92 | 34.62 | 34.62 | 3.85 | 3.85 | 19.23 |
| Main | aware | 23.08 | 23.08 | 30.77 | 15.38 | 11.54 | 23.08 | 7.69 |
| Main | very | 3.85 | 30.77 | 15.38 | 15.38 | 19.23 | 23.08 | 23.08 |
| Main | strongly | 3.85 | 0.00 | 7.69 | 3.85 | 61.54 | 46.15 | 42.31 |
| n=26 | no reponse | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 8.00 |
| | | | | | | | | |
| Madaba | not aware | 35.56 | 13.33 | 11.11 | 6.67 | 15.56 | 8.89 | 22.22 |
| Madaba | Somewhat | 46.67 | 37.78 | 26.67 | 42.22 | 17.78 | 20.00 | 33.33 |
| Madaba | aware | 6.67 | 28.89 | 26.67 | 22.22 | 15.56 | 22.22 | 11.11 |
| Madaba | very | 8.89 | 13.33 | 24.44 | 17.78 | 13.33 | 17.78 | 11.11 |
| Madaba | strongly | 2.22 | 4.44 | 11.11 | 8.89 | 37.78 | 31.11 | 15.56 |
| n=45 | no response | 0.00 | 2.00 | 0.00 | 2.00 | 0.00 | 0.00 | 7.00 |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Amman | not aware | 53.73 | 37.31 | 37.31 | 13.43 | 16.42 | 28.36 | 32.84 |
| Amman | Somewhat | 23.88 | 34.33 | 23.88 | 34.33 | 22.39 | 23.88 | 31.34 |
| Amman | aware | 14.93 | 16.42 | 11.94 | 25.37 | 23.88 | 13.43 | 11.94 |
| Amman | very | 2.99 | 5.97 | 19.40 | 14.93 | 17.91 | 19.40 | 10.45 |
| Amman | strongly | 2.99 | 2.99 | 2.99 | 10.45 | 17.91 | 11.94 | 4.48 |
| n=67 | no resonse | 1.00 | 3.00 | 4.00 | 1.00 | 1.00 | 3.00 | 7.00 |

**Appendix D-1: Average water depths at water stations**

| | 1986 Depth to Water and Water Level Averages | | |
|---|---|---|---|
| STATION_ID | STATION_NAME | DEPTH_TO_WATER | WATER_LEVEL |
| AL1300 | AWAJAN OBSERVATION | 33.892 | 561.438 |
| AL1444 | AIN EL REUEIFA 8 /OBSERVATION | 6.974 | 593.026 |
| AL1734 | ZERQA OBSERVATION 1 | 55.828 | 504.372 |
| AL1782 | RACE CLUB NO 13 | 101.232 | 683.948 |
| CD1075 | QASTAL NO 7 (OBS.) | 178.4666667 | 566.5333333 |
| CD1097 | WALA NO 11 OBSERVATION | 8.721818182 | 335.4281818 |
| CD1100 | WALA NO 14 | 26.15 | 450.26 |
| CD1136 | DABB'A NO (S 70) | 154.7833333 | 585.5166667 |
| CD1197 | ARAINBEH NO 4(OBS.) | 170.375 | 540.825 |
| CD1212 | BREAK OBS. NO 1 | 161.275 | 548.075 |
| CD1213 | UM EL RASAS OBS. NO 1 | 195.53 | 571.82 |
| | | | |

| | 1991 Depth to Water and Water Level Averages | | |
|---|---|---|---|
| STATION_ID | STATION_NAME | DEPTH_TO_WATER | WATER_LEVEL |
| AL1300 | AWAJAN OBSERVATION | 36.858 | 558.472 |
| AL1444 | AIN EL RUSEIFA 8 /OBSERVATION | 7.714 | 592.286 |
| AL1734 | ZERQA OBSERVATION 1 | 54.376 | 505.824 |
| AL1782 | RACE CLUB NO 13 | 97.028 | 688.152 |
| CD1075 | QASTAL NO 7 (OBS.) | 181.06 | 563.94 |
| CD1087 | WALA NO 11 OBSERVATION | 10.12 | 334.03 |
| CD1100 | WALA NO 14 | 29.838 | 446.573 |
| CD1136 | DABB'A NO (S 70) | 157.2 | 583.1 |
| CD1137 | WADI HAMMAM NO 4 (PP 86) | 81.275 | 627.875 |
| CD1197 | ARAINBEH NO 4(OBS.) | 184.55 | 526.65 |
| CD1212 | BREAK OBS. NO 1 | 166.057 | 543.293 |
| CD1213 | UM EL RASAS OBS. NO 1 | 200.945 | 566.405 |

| | 1998 Depth to Water and Water Level Averages | | |
|---|---|---|---|
| STATION_ID | STATION_NAME | DEPTH_TO_WATER | WATER_LEVEL |
| AL1300 | AWAJAN OBSERVATION | 34.78916667 | 560.5408333 |
| AL1444 | AIN EL RUSEIFA 8 /OBSERVATION | 6.545833333 | 593.4541667 |
| AL1734 | ZERQA OBSERVATION 1 | 53.20333333 | 506.9966667 |
| AL1782 | RACE CLUB NO 13 | 93.03333333 | 692.1466667 |
| AL1792 | MADOUNEH NO4 | 146.8725 | 633.2775 |
| AL1813 | AWSA 5 NOUREDDEEN | 13.515 | 712.705 |
| AL3349 | WADI EL QATTAR 7 | 111.1891667 | 678.9808333 |
| AL2714 | RACE CLUB NO 18 | 64.82 | 675.18 |
| AL3386 | RUSEIFA LANDFILL MONITORING 3 | 28.8 | 613.71 |
| AL3391 | TAFEH SOUTH MONITORING 2 | 134.306 | 561.424 |

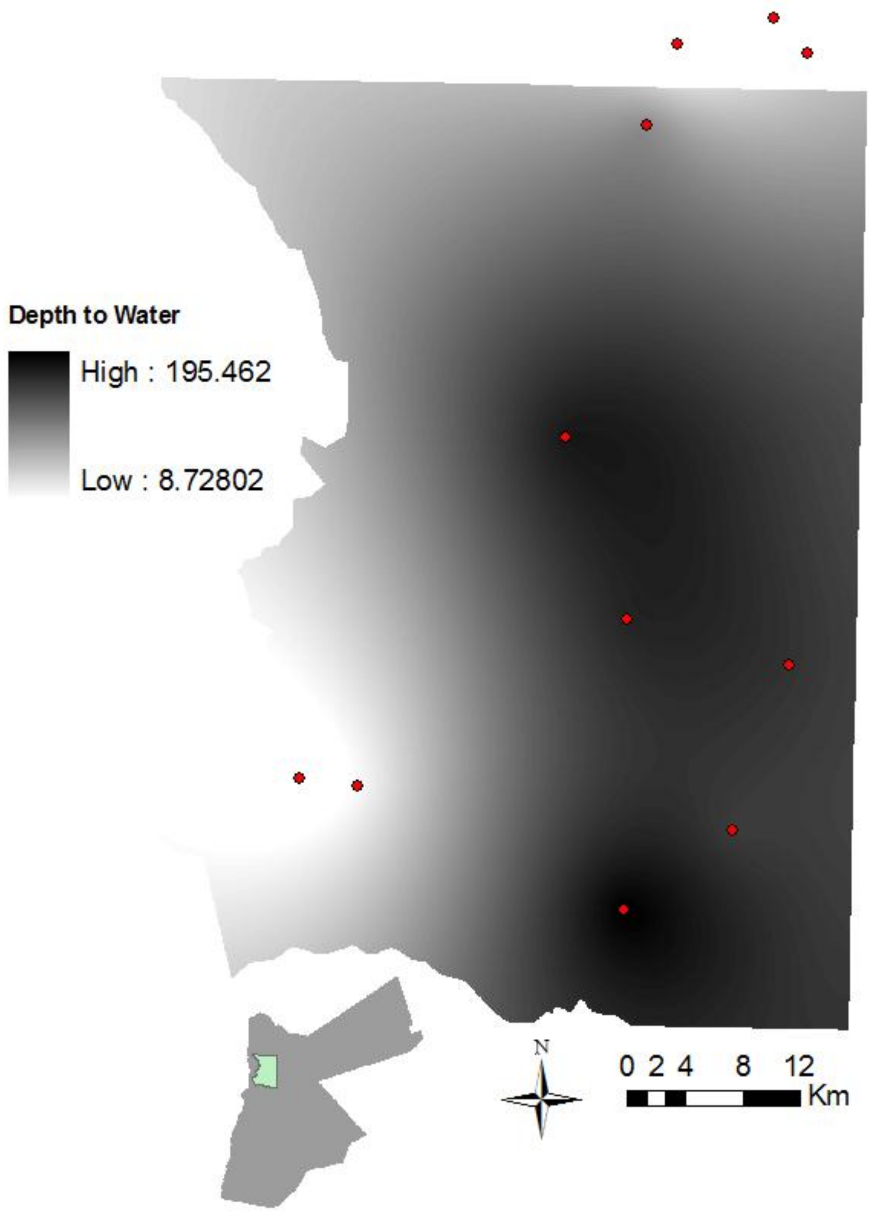
| | | | |
|---|---|---|---|
| CD1075 | QASTAL NO 7 (OBS.) | 189.0263636 | 555.9736364 |
| CD1097 | WALA NO 11 OBSERVATION | 9.529166667 | 334.6208333 |
| CD1136 | DABB'A NO (S 70) | 163.877 | 576.423 |
| CD1137 | WADI HAMMAM NO 4 (PP 86) | 81.7 | 627.45 |
| CD3133 | HEEDAN NO 2(OBSERVATION) | 21.02166667 | 399.4783333 |

| | 02 Depth to Water and Water Level Averages | | |
|---|---|---|---|
| STATION_ID | STATION_NAME | DEPTH_TO_WATER | WATER_LEVEL |
| AL1300 | AWAJAN OBSERVATION | 50.885 | 544.445 |
| AL1351 | RUSEIFA MUNICIPALITY 1 | 26.479 | 593.521 |
| AL1444 | AIN EL RUSEIFA 8 /OBSERVATION | 6.516 | 593.484 |
| AL1548 | AWSA SEIL EL RUSAIFEH NO 3 | 145.326 | 512.824 |
| AL1637 | YAJUZ NO 1 | 139.475 | 667.525 |
| AL1641 | YAJUZ NO 6 | 18.375 | 856.625 |
| AL1734 | ZERQA OBSERVATION 1 | 55.400 | 504.800 |
| AL1782 | RACE CLUB NO 13 | 99.328 | 685.852 |
| AL1792 | MADOUNEH NO4 | 146.928 | 633.222 |
| AL1813 | AWSA 5 NOUREDDEEN | 18.199 | 708.021 |
| AL1851 | MERCURY 5 | 62.127 | 638.573 |
| AL2690 | AIN GHAZAL STATION 2 (NEW) | 38.710 | 661.290 |
| AL2714 | RACE CLUB NO 18 | 67.900 | 672.100 |
| AL3324 | AIN GHAZAL DEEP NO 4 | 149.442 | 610.808 |
| AL3343 | WADI EL QATTAR 1 | 73.440 | 666.860 |
| AL3349 | WADI EL QATTAR 7 | 110.722 | 679.448 |
| AL3386 | RUSEIFA LANDFILL MONITORING 3 | 29.412 | 613.098 |
| AL3391 | TAFEH SOUTH MONITORING 2 | 136.241 | 559.489 |
| AL3392 | WADI I'SHASH MONITORING 1 | 58.637 | 561.793 |
| AL3430 | MAQARR INVESTIGATION 14B | 29.726 | 695.724 |
| AL3520 | YAJUZ 1 MONITORING | 49.661 | 880.689 |
| AL3523 | RUSEIFA MONITORING 1 | 191.324 | 549.726 |
| CC1014 | MADABA WASTEWATER T.PLANT 1 | 199.210 | 531.890 |
| CC1015 | MADABA WASTEWATER T.PLANT 2 | 213.804 | 520.246 |
| CD1075 | QASTAL NO 7 (OBS.) | 211.327 | 533.673 |
| CD1097 | WALA NO 11 OBSERVATION | 16.100 | 328.050 |
| CD1100 | WALA NO 14 | 115.483 | 360.927 |
| CD1136 | DABB'A NO (S 70) | 175.957 | 564.343 |
| CD1137 | WADI HAMMAM NO 4 (PP 86) | 82.155 | 626.995 |
| CD1197 | ARAINBEH NO 4(OBS.) | 216.400 | 494.800 |
| CD1212 | BREAK OBS. NO 1 | 181.357 | 527.993 |
| CD1213 | UM EL RASAS OBS. NO 1 | 205.317 | 562.033 |
| CD3125 | ABU E'LAYYAN OBS | 151.347 | 510.903 |
| CD3133 | HEEDAN NO 2(OBSERVATION) | 45.766 | 374.734 |
| CD3230 | DHUHEIBA AL SHARQIYA NO 3 | 202.598 | 589.603 |
| CD3340 | KHAN EL ZABEEB MONITORING | 238.325 | 541.675 |
| F 3755 | MUWAQQAR(KM 6) | 297.813 | 507.187 |

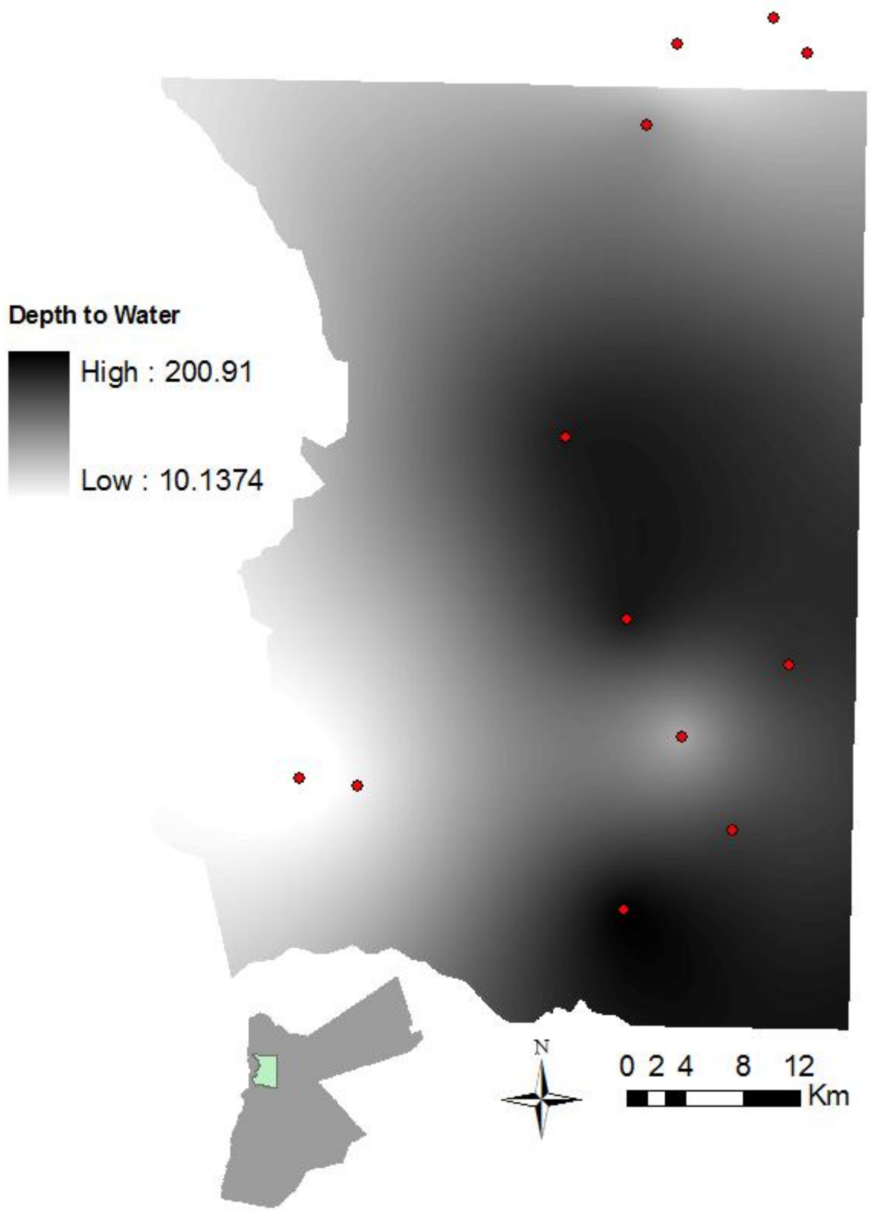
| | | | |
|---|---|---|---|
| | | | |

| | 07 Depth to Water and Water Level Averages | | |
|---|---|---|---|
| STATION_ID | STATION_NAME | DEPTH_TO_WATER | WATER_LEVEL |
| AL1300 | AWAJAN OBSERVATION | 57.54 | 537.79 |
| AL1351 | RUSEIFA MUNICIPALITY 1 | 37.54333333 | 582.4566667 |
| AL1444 | AIN EL RUSEIFA 8 /OBSERVATION | 5.58 | 594.42 |
| AL1637 | YAJUZ NO 1 | 138.8566667 | 668.1433333 |
| AL1641 | YAJUZ NO 6 | 5.86 | 869.14 |
| AL1734 | ZERQA OBSERVATION 1 | 57.3725 | 502.8275 |
| AL1782 | RACE CLUB NO 13 | 102.3575 | 682.8225 |
| AL1790 | MADOUNEH NO 2 | 187.84 | 632.9 |
| AL1791 | MADOUNEH NO3 | 85.21 | 650.63 |
| AL1792 | MADOUNEH NO4 | 150.88 | 629.27 |
| AL1813 | AWSA 5 NOUREDDEEN | 14.66416667 | 711.5558333 |
| AL1851 | MERCURY 5 | 61.78 | 638.92 |
| AL2690 | AIN GHAZAL STATION 2 (NEW) | 36.69857143 | 663.3014286 |
| AL2714 | RACE CLUB NO 18 | 68.78666667 | 671.2133333 |
| AL3324 | AIN GHAZAL DEEP NO 4 | 142.86 | 617.39 |
| AL3343 | WADI EL QATTAR 1 | 74.548 | 665.752 |
| AL3349 | WADI EL QATTAR 7 | 110.4708333 | 679.6991667 |
| AL3386 | RUSEIFA LANDFILL MONITORING 3 | 32.63857143 | 609.8714286 |
| AL3391 | TAFEH SOUTH MONITORING 2 | 132.8366667 | 562.8933333 |
| AL3392 | WADI I'SHASH MONITORING 1 | 56.68 | 563.75 |
| AL3430 | MAQARR INVESTIGATION 14B | 25.9925 | 699.4575 |
| AL3520 | YAJUZ 1 MONITORING | 50.1875 | 880.1625 |
| AL3523 | RUSEIFA MONITORING 1 | 197.875 | 528.675 |
| AL3725 | SUPPLY OBSERVATION | 135.2058333 | 510.3641667 |
| CC1014 | MADABA WASTEWATER T.PLANT 1 | 200.2171429 | 530.8828571 |
| CC1015 | MADABA WASTEWATER T.PLANT 2 | 217.8025 | 516.2475 |
| CD1075 | QASTAL NO 7 (OBS.) | 212.2741667 | 532.7258333 |
| CD1097 | WALA NO 11 OBSERVATION | 2.845 | 341.305 |
| CD1136 | DABB'A NO (S 70) | 188.088 | 552.212 |
| CD1137 | WADI HAMMAM NO 4 (PP 86) | 76.762 | 632.388 |
| CD1197 | ARAINBEH NO 4(OBS.) | 224.6890909 | 486.5109091 |
| CD1212 | BREAK OBS. NO 1 | 187.935 | 521.415 |
| CD1213 | UM EL RASAS OBS. NO 1 | 223.77 | 543.58 |
| CD3125 | ABU E'LAYYAN OBS | 169.6709091 | 492.5790909 |
| CD3133 | HEEDAN NO 2(OBSERVATION) | 7.959090909 | 412.5409091 |
| CD3340 | KHAN EL ZABEEB MONITORING | 239.7416667 | 540.2583333 |
| F 3755 | MUWAQQAR(KM 6) | 312.385 | 492.615 |

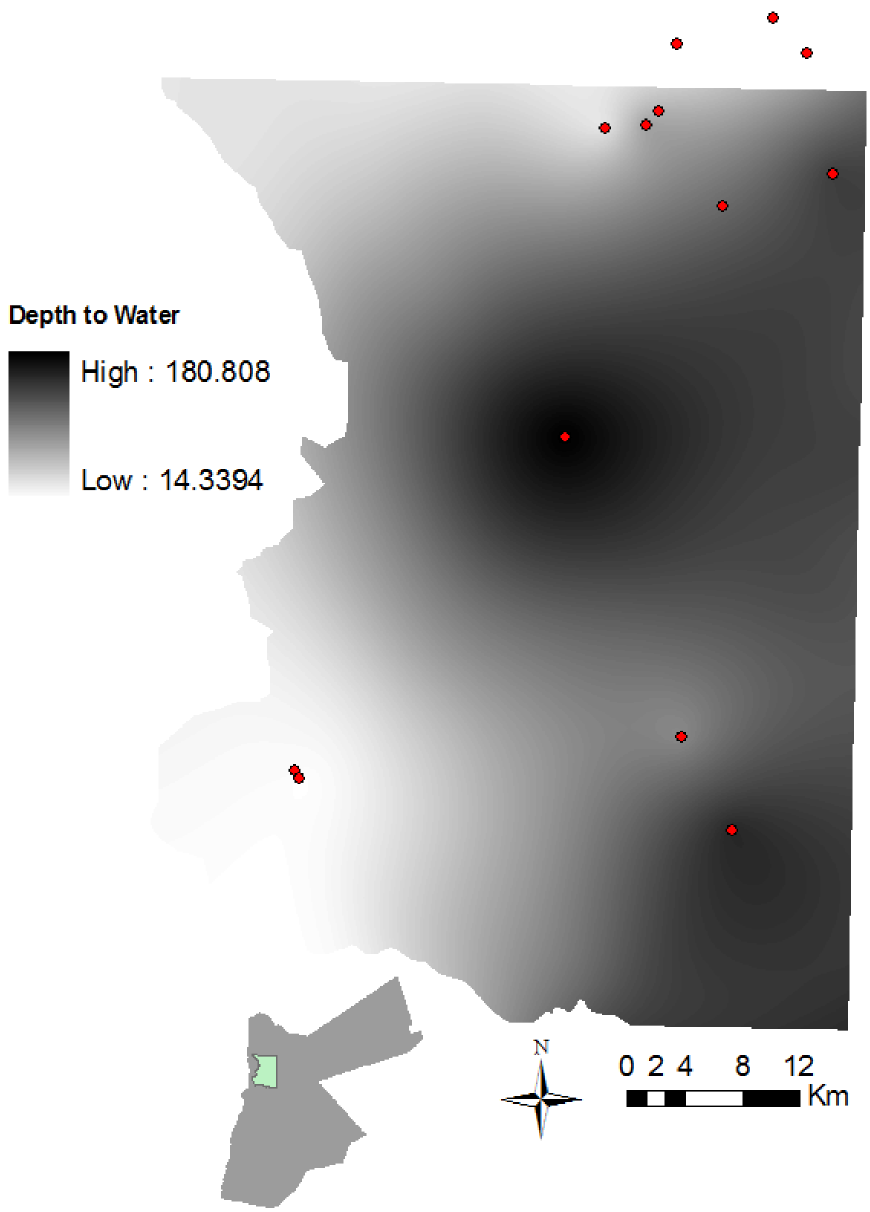
## Appendix D-2: Distribution of Well Points and Yearly Depth to Water



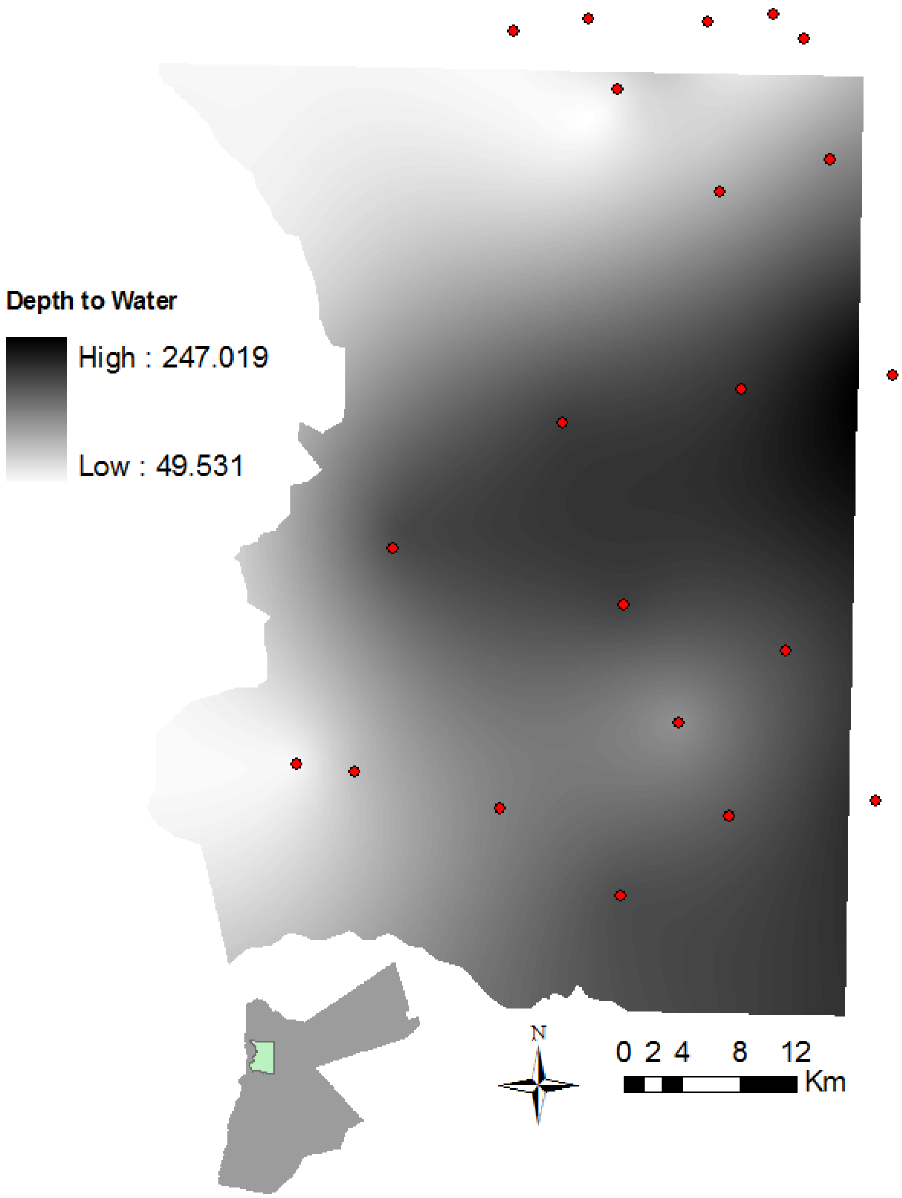

1986 Depth to water measurements and observation well points.



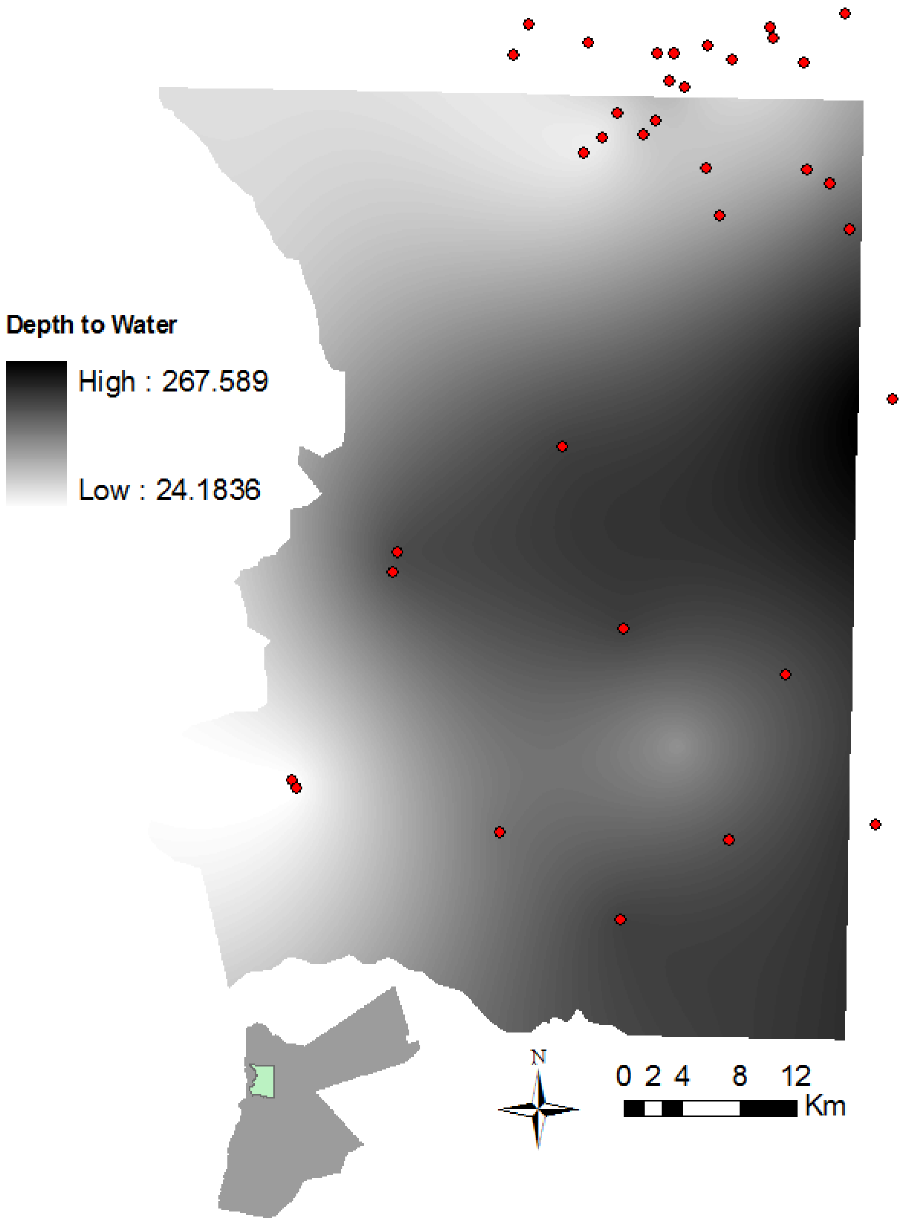

1991 Depth to water measurements and observation well points.




1998 Depth to water measurements and observation well points.




2002 Depth to water measurements and observation well points.




2007 Depth to water measurements and observation well points.

## Appendix E - Spearman's Rho Correlation Table

| | | Land Ownership History | Marital Status | Income | Age | Education | Overpumping Aquifers | Water Mining | Water Quality | Water Runoff | Desertification | Methods/ Tecnologies | Landuse Change |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Land Ownership History | Correlation Coefficient | 1.000 | .117 | .002 | .105 | .014 | .139* | -.021 | .054 | .053 | .231** | .228** | .256** |
| | Sig. (2-tailed) | . | .091 | .979 | .132 | .845 | .044 | .758 | .444 | .446 | .001 | .001 | .000 |
| | N | 211 | 210 | 185 | 206 | 200 | 211 | 209 | 207 | 209 | 209 | 207 | 197 |
| Marital Status | Correlation Coefficient | .117 | 1.000 | .014 | .429** | -.034 | -.049 | -.029 | .016 | -.006 | .158* | .155* | .185** |
| | Sig. (2-tailed) | .091 | . | .848 | .000 | .624 | .466 | .673 | .809 | .928 | .019 | .022 | .008 |
| | N | 210 | 223 | 193 | 217 | 212 | 222 | 219 | 218 | 219 | 220 | 218 | 208 |
| Income | Correlation Coefficient | .002 | .014 | 1.000 | .185* | .296** | .027 | .126 | .156* | .231** | -.033 | -.044 | .028 |
| | Sig. (2-tailed) | .979 | .848 | . | .011 | .000 | .713 | .084 | .032 | .001 | .648 | .549 | .705 |
| | N | 185 | 193 | 194 | 189 | 185 | 193 | 190 | 189 | 190 | 191 | 189 | 181 |
| Age | Correlation Coefficient | .105 | .429** | .185* | 1.000 | .192** | .056 | .008 | .120 | .095 | .174* | .362** | .258** |
| | Sig. (2-tailed) | .132 | .000 | .011 | . | .005 | .414 | .913 | .079 | .164 | .010 | .000 | .000 |
| | N | 206 | 217 | 189 | 218 | 208 | 218 | 215 | 214 | 215 | 216 | 214 | 204 |
| Education | Correlation Coefficient | .014 | -.034 | .296** | .192** | 1.000 | .122 | .318** | .154* | .301** | .194** | .134 | .208** |
| | Sig. (2-tailed) | .845 | .624 | .000 | .005 | . | .076 | .000 | .027 | .000 | .005 | .053 | .003 |
| | N | 200 | 212 | 185 | 208 | 213 | 212 | 209 | 208 | 209 | 210 | 208 | 198 |
| Overpumping Aquifers for Agriculture | Correlation Coefficient | .139* | -.049 | .027 | .056 | .122 | 1.000 | .327** | .295** | .228** | .089 | .252** | .206** |
| | Sig. (2-tailed) | .044 | .466 | .713 | .414 | .076 | . | .000 | .000 | .001 | .190 | .000 | .003 |
| | N | 211 | 222 | 193 | 218 | 212 | 223 | 220 | 219 | 220 | 221 | 219 | 209 |
| Water Mining | Correlation Coefficient | -.021 | -.029 | .126 | .008 | .318** | .327** | 1.000 | .264** | .219** | .169* | .142* | .200** |
| | Sig. (2-tailed) | .758 | .673 | .084 | .913 | .000 | .000 | . | .000 | .001 | .012 | .037 | .004 |
| | N | 209 | 219 | 190 | 215 | 209 | 220 | 220 | 216 | 218 | 219 | 216 | 207 |
| Water | Correlation | .054 | .016 | .156* | .120 | .154* | .295** | .264** | 1.000 | .200** | .260** | .220** | .240** |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quality | Coefficient | | | | | | | | | | | | |
| | Sig. (2-tailed) | .444 | .809 | .032 | .079 | .027 | .000 | .000 | . | .003 | .000 | .001 | .000 |
| | N | 207 | 218 | 189 | 214 | 208 | 219 | 216 | 219 | 216 | 218 | 216 | 207 |
| Water Runoff | Correlation Coefficient | .053 | -.006 | .231** | .095 | .301** | .228** | .219** | .200** | 1.000 | .144* | .130 | .201** |
| | Sig. (2-tailed) | .446 | .928 | .001 | .164 | .000 | .001 | .001 | .003 | . | .033 | .056 | .004 |
| | N | 209 | 219 | 190 | 215 | 209 | 220 | 218 | 216 | 220 | 219 | 216 | 207 |
| Desertification | Correlation Coefficient | .231** | .158* | -.033 | .174* | .194** | .089 | .169* | .260** | .144* | 1.000 | .414** | .374** |
| | Sig. (2-tailed) | .001 | .019 | .648 | .010 | .005 | .190 | .012 | .000 | .033 | . | .000 | .000 |
| | N | 209 | 220 | 191 | 216 | 210 | 221 | 219 | 218 | 219 | 221 | 218 | 209 |
| Methods/Tecnologies | Correlation Coefficient | .228** | .155* | -.044 | .362** | .134 | .252** | .142* | .220** | .130 | .414** | 1.000 | .556** |
| | Sig. (2-tailed) | .001 | .022 | .549 | .000 | .053 | .000 | .037 | .001 | .056 | .000 | . | .000 |
| | N | 207 | 218 | 189 | 214 | 208 | 219 | 216 | 216 | 216 | 218 | 219 | 207 |
| Landuse Change | Correlation Coefficient | .256** | .185** | .028 | .258** | .208** | .206** | .200** | .240** | .201** | .374** | .556** | 1.000 |
| | Sig. (2-tailed) | .000 | .008 | .705 | .000 | .003 | .003 | .004 | .000 | .004 | .000 | .000 | . |
| | N | 197 | 208 | 181 | 204 | 198 | 209 | 207 | 207 | 207 | 209 | 207 | 209 |

## Appendix F – Continuity Values per grid per year

| ***Grid Number*** | ***1991*** | ***1998*** | ***2002*** | ***2007*** |
|---:|---:|---:|---:|---:|
| 0 | 0.027128 | 0.057715 | 0.026951 | 0.023738 |
| 1 | 6.669813 | 0.341372 | 0.15376 | 0.078022 |
| 2 | 0.195439 | 0.092223 | 0.006501 | 0.030122 |
| 3 | 0.143702 | 0.062553 | 0.006234 | 0.233433 |
| 4 | 0 | 0.012412 | 0.031726 | 0.214505 |
| 5 | 0.027892 | 0.032066 | 0.047931 | 0.012351 |
| 6 | 0.065408 | 0.190783 | 0.219737 | 0.051388 |
| 7 | 0.065308 | 0.078155 | 0.013346 | 0.107717 |
| 8 | 0.341859 | 0.128717 | 0.01182 | 0.145727 |
| 9 | 0.110002 | 0.079996 | 0.012537 | 0.23443 |
| 10 | 0.348562 | 0.172105 | 0.397206 | 0.022567 |
| 11 | 3.28431 | 1.551629 | 1.843962 | 0.547143 |
| 12 | 0.603427 | 0.327274 | 0.11693 | 0.094462 |
| 13 | 0.538076 | 0.278703 | 0.065119 | 0.138373 |
| 14 | 0.263703 | 0.166872 | 0.026973 | 0.336729 |
| 15 | 2.00491 | 1.183777 | 1.065541 | 0.304639 |
| 16 | 2.405948 | 1.262881 | 1.405554 | 0.53262 |
| 17 | 0.278803 | 0.279886 | 0.191506 | 0.115277 |
| 18 | 0.086366 | 0.036512 | 0.012606 | 0.062118 |
| 19 | 0.222195 | 0.114767 | 0.161221 | 0.210543 |
| 20 | 0.693695 | 0.294724 | 0.396558 | 0.341811 |
| 21 | 1.043463 | 0.511818 | 0.371229 | 0.123496 |
| 22 | 0.0888 | 0.131117 | 0.047954 | 0.030016 |
| 23 | 0.010879 | 0.054078 | 0.007089 | 0.060604 |

## Appendix G: Summary of Results

| | | | | | |
|---|---|---|---|---|---|
| **Sex:** | Male: 62.5% | Female: 34.4% | NR: 4.5% | | |
| **Age:** | <20yrs: 13.8% | 21-25yrs: 16.5% | 26-30yrs: 18.8% | 31-35yrs: 9.8% | 35-40yrs: 8% |
| | 41-45yrs: 4.9% | 46-50yrs: 4.9% | 51-55yrs: 4.5% | 56-60yrs: 7.6% | >60: 8.5% |
| **Land Ownership History** | 1-2yrs: 9.8% | 3-4yrs: 9.4% | 5-6yrs: 13.8% | 7-8yrs: 8.5% | 9-10yrs: 14.3% |
| | >10yrs: 38.4% | NR: 5.8% | | | |
| **Marital Status:** | Single: 39.3% | Married: 46% | Widow/Widower: 14.3% | NR: .4% | |
| **Income:** | <$15,000: 56.2% | $15,001-$20,000: 16.1% | $20,001-$25,000: 9.8% | $25,001-$30,000: 4% | >$30,000: .4% |
| | NR: 13.4% | | | | |
| **Education:** | High School: 48.2% | Some College: 14.3% | College Grad: 18.8% | Some Grad School: 3.6% | Masters or Ph.D:10.3% |
| | NR: 4.9% | | | | |
| **Employment:** | Full-time: 12.5% | Part-time: 16.5% | Managerial: 6.7% | Private Firm: 16.5% | Pub agency: 21.4% |
| | Self Empl.: 18.8% | NR: 7.6% | | | |
| **Overpumping Aquifers for Agriculture:** | Not Aware: 46.9% | Somewhat Aware: 31.7% | Aware: 12.5% | Very Aware: 5.4% | Strongly Aware: 3.1% |
| | NR: .4% | | | | |
| **Water Mining:** | Not Aware: 21.9% | Somewhat Aware: 35.3% | Aware: 22.8% | Very Aware:13.4% | Strongly Aware: 4.9% |
| | NR: 1.8% | | | | |
| **Water Quality:** | Not Aware: 19.2% | Somewhat Aware: 26.8% | Aware: 22.8% | Very Aware: 19.6% | Strongly Aware: 9.4% |
| | NR: 2.2% | | | | |
| **Water Runoff:** | Not Aware: 15.6% | Somewhat Aware: 33% | Aware: 21% | Very Aware: 18.8% | Strongly Aware: 9.8% |
| | NR: 1.8% | | | | |
| **Desertification:** | Not Aware: 14.7% | Somewhat Aware: 21% | Aware: 16.5% | Very Aware: 17.4% | Strongly Aware: 29% |
| | NR:1.3% | | | | |
| **Methods/Technologies:** | Not Aware: 18.8% | Somewhat Aware: 20.5% | Aware: 21.4% | Very Aware: 16.1% | Strongly Aware: 21% |
| | NR: 2.2% | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Landuse Change:** | Not Aware: 25.9% | Somewhat Aware: 23.2% | Aware: 15.2% | Very Aware: 13.4% | Strongly Aware:15. 6% |
| | NR: 6.7% | | | | |

## Appendix H- Pictures from the Madaba Plain

**Figure H-1:** Inside of a green house on the Madaba plain.  Drip agriculture is implemented.

**Figure H-2:** Wheat field near Ma'in. These large fields are standard throughout the Madaba Plain.  During times of drought, low quality wheat is

**Figure H-3:** Zucchini farm on the outskirts of Amman.

**Figure H-4:** Rows of Greenhouses near the airport. These greenhouses help control climate for vegetation sensitive to environmental stresses.

**Figure H-5:** Farm with green houses in the backdrop.

**Figure H-6:** Apple orchid with supplementary vegetable growth. This orchid institutes drip irrigation. A number of multi cropped plots were found on the Madaba Plain.

**Figure H-7:** Small scale agricultural plot. This type of land use is typical for residential areas.

**Figure H-8:** Vegetable farm on the Madaba Plain. Note the color of the soils. This type of soil is widespread over the Madaba Plain.

**Figure H-9:** Aqueduct shared by multiple farmers. Farmers pay the municipality for use.

**Figure H-10:** Offshoot of previous aqueduct.  Note the leakage occurring. Farmers take turns opening the sluice gates that lead to their plots.

**Figure H-11:** Above ground reservoir.

**Figure H-12:** Wall of an above ground reservoir built from concrete. This is a permanent structure and is not typical of the area.

**Figure H-13:** Open air reservoir with plastic tarp lining. Location in the Jordan Valley. This is more typical of reservoirs in the area.

**Figure H-14:** Ditch being prepared for drip agriculture implementation.

**Figure H-15:** Well head with a hose. The hose leads to a pump that is in the aquifer.

**Figure H-16:** Pit being prepared for farming dates. Location in the Jordan Valley.

**Figure H-17:** Recently planted date tree.

**Figure H-18:** Young date tree. This particular farmer stated that he preferred these trees as they are easier to harvest.

**Figure H-19:** Unripe dates. Dates at this stage are edible but very bitter.

**Figure H-20:** Extreme soil salinization. This was due to traditional irrigation practices. Note the shift to drip irrigation.

**Figure H-21:** More salinization.  Note the hose that is used for irrigation.

**Figure H-22:** Pigeon coop on a livestock farm. Small livestock is often raised on crop farms.

**Figure H-23:** Empty livestock farm. This particular one was used to house sheep.

**Figure H-24:** Terracing of olive trees. Terracing is often implemented in areas of high relief.

**Figure H-25:** Yasine and his son, Omar.  Yasine helped with administering a number of surveys in the Madaba and Um al-Basateen region.

**Figure H-26:** Sami al-Sheikh helped me with transportation and initiating contact with a number of farmers.

**Figure H-27:** A study participant on horseback. This respondent lived traditionally even though they also own a permanent house.

**Figure H-28:** Abu and Um Ra'id.  They helped with introductions in Ma'in and with distribution of written surveys.

**Figure H-29:** Ahmed and son.  Ahmed helped with data collection of GPS points for ground trothing, as well as distribution of the written surveys.

**Figure H-30:** Abdelrazak from Na'oor.